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HOW TO MAKE
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DYNAMOS AND ELECTRIC MOTORS


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DYNAMOS AND ELECTRIC MOTORS

HOW TO MAKE AND RUN THEM

WITH NUMEROUS ENGRAVINGS AND DIAGRAMS

EDITED BY

PAUL N. HASLUCK

EDITOR OF "WORK" AND "BUILDING WORLD,"
AUTHOR OF "HANDYBOOKS FOR HANDICRAFTS," ETC. ETC.

PHILADELPHIA
DAVID McKAY, PUBLISHER
1022, *MARKET STREET*
1903

PREFACE.

THIS Handbook contains, in a form convenient for everyday use, a comprehensive digest of the information on How to Make and Run Small Dynamos and Electric Motors, scattered over ten thousand columns of WORK, one of the weekly journals it is my fortune to edit—and supplies concise information on the general principles of the subjects on which it treats.

In preparing for publication in book form the mass of relevant matter contained in the volumes of WORK, much that was tautological in character had to be rejected. The remainder necessarily had to be arranged anew, altered and largely re-written. From these causes the contributions of many are so blended that the writings of individuals cannot be distinguished for acknowledgment.

Readers who may desire additional information respecting special details of the matters dealt with in this Handbook, or instruction on kindred subjects, should address a question to WORK, so that it may be answered in the columns of that journal.

P. N. HASLUCK.

La Belle Sauvage, London.

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DYNAMOS & ELECTRIC MOTORS.

CHAPTER I.

INTRODUCTION.

Since the invention of the first dynamo in 1832, by Pixii, the machine has passed through many phases of evolution. It began under the name of a magneto-electric machine, and continued to bear this name whilst permanent steel magnets were employed in its construction. It was then as truly a dynamo as any one of its successors, because the permanent magnets only acted as required when moved. It is not intended in this Handbook to give a history of the machine, but to show how to make small examples of those which are now in general use for electric lighting purposes. These may be arranged in classes named according to the types of armatures, or of the field magnets used in their construction.

Before describing either the dynamo or its action, it would be as well to consider when and why the dynamo-electric machine is used, instead of primary batteries, as a means of generating electricity for lighting lamps, etc. In the first place, the lighting of electric lamps by the agency of primary batteries is only practicable under somewhat restricted conditions. To get a sufficiently high electro motive force it is necessary to have a great number of cells connected in series, and big cells are required to provide the current, or the battery will soon run down. When a cell is required to give a current of three ampères or more, it polarises very rapidly; hence to lower the resistance of the lamp circuit (as by placing the lamps in parallel) is costly and inconvenient, as a greater demand for current is thus thrown on the battery. Then the costly, dirty, and laborious job of cleaning and recharging the cells is enough to make one wish for some better method of generating the electric current.

Small electric lights, such as night-lights and occasional lights of low candle power, may be fed with a small two-cell chromic acid battery, or even a Fuller bichromate battery. But when the area of lighting is extended, a dynamo-electric machine is generally used. This is a machine for converting mechanical energy into electric energy.

There are many who believe that electricity actually runs, or flows, from one end of a wire or conductor to the other, in a certain direction, when the ends are connected to a battery or dynamo. For instance, in the case of a battery of primary cells, the current is always spoken of as coming from the carbon terminal, going through the external circuit, and returning to the zinc. This, in point of fact, is misleading; for the expression is quite conventional, and it might easily have been expressed the other way, and would have made no difference whatever to electrical formulæ or laws. But when electricity came to be studied and advance was made in the science, it was mutually agreed to express the phenomenon in this way.

In a similar manner it was agreed to call one end of a magnet the north pole, and the other the south; but in this case we are brought face to face with a paradox. It is this: either we have all along been giving our magnet ends wrong names, or else Franklin, and many others after him, have diligently been searching the Arctic Seas for the North Pole when it is the south all the time; for like poles repel each other, unlike poles attract. Perhaps it has been noticed that many writers are careful in calling the two ends of a magnet the north-seeking and south-seeking poles respectively.

But as regards an electric current, this conventional way of expressing it must not be taken literally. Electricity is not a liquid; it does not flow through a certain wire as water through a pipe. Although water is a very useful substance to make use of as an example when studying some of the phenomena of electricity, yet electricity is unlike water in many ways —it can be said to work uphill; it is not influenced by the force of gravity; also, it can be said to act two ways at once.

Whatever electricity may be, it is perfectly clear at the present time that sources of electrical energy have different effects upon different substances, copper, silver, and other metals being very susceptible to this influence. Hence, these metals are called the best conductors. But glass, vulcanite, paraffin wax, and most compound substances are considered, in one sense, bad conductors—some say non-conductors.

The actual time it takes a current of electricity to traverse a given length of wire is often stated and put down to be some fraction of a second; but it must on no account be understood from this that the current flows from its source in one direction right round the circuit and back again to that source; but that a "condition" is set up, when the circuit is closed, both ways along the conductor or wire.

As far as we know, in an electric circuit nothing can actually be said to flow from one end to the other, but it is a "condition" set up throughout the entire length; and this length must form a complete circuit or ring, the shape of which matters little. Also, somewhere within this circuit, and forming part of it, must be placed the means of setting up this "condition" —say, a battery or a dynamo.

The following outlines represent the field magnets of some dynamos in general use :—Undertype, Fig. 1: Two vertical cores of rectangular section joined to the pole-pieces, cast with armature tunnel in lower part Similar machines have cores of circular section. Overtype, Fig. 2: Two vertical cores of suitable section cast with yoke at base, and the armature tunnel in upper part. Coils may be wound separately, then slipped over cores. Several modifications of this machine have been designed. Some of these have round cores. Single coil or simplex, Fig. 3 : One core of circular section joined to suitable pole-pieces with the armature tunnel at the side. In one form this machine has its single core spanning horizontally the two vertical pole-pieces, with the armature tunnel in the upper part. Manchester, Fig. 4 : Two cores of circular section bedded into two horizontal pole-pieces. Armature tunnel in the central part of the machine between the two cores. Gramme, Fig. 5 : Four horizontal cores of circular section bedding into massive pole-pieces in the centre of the machine, and into vertical standards at the sides ; armature tunnel in centre of the machine.

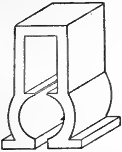


Fig. 1.—Undertype Field Magnet.

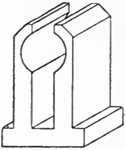


Fig. 2.—Overtype Field Magnet.

The field magnets of these machines are not made up of steel permanently magnetised, but are constructed of comparatively soft iron, containing residual magnetism, which, by dynamic energy imparted to the armature, is induced to exert its influence on the armature coils, and create in them an electric current. This current, or part of it, is then sent around the field magnet coils, with the result that a stronger magnetism is induced in the cores of the field magnets. Being thus strengthened, they induce a higher electro-motive force in the armature coils, and thus the full electric power of the machine is worked up

Now as to the way in which a current of electricity is measured. The unit of current generally accepted is the Ampère. Some idea of its meaning may be learned by comparison with other units of measurement. For instance, in trades where the foot rule is used, the foot and inch are units of measurement of length. Where steam engines are used, we speak of pounds per square inch in estimating the pressure of steam; and horse-power as a unit in estimating the power of a steam engine. Where water is used as a motive power, we speak of its volume by cubic inches, or gallons. In dealing with electrical measurements, neither the foot rule nor the spring-pressure gauge can be used, so electricians have had to invent a new set of instruments, and new names for the units or divisions marked on them.

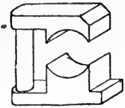


Fig. 3.—Single Coil or Simplex Field Magnet.

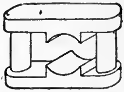


Fig. 4.—Manchester Field Magnet.

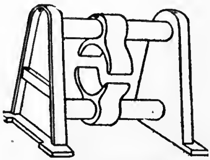


Fig. 5.—Gramme Field Magnet.

The *Ampère* is defined as that current which is obtained when an electro-motive force of one *Volt* acts on a resistance of one *Ohm.* A volt is the unit measure of electro-motive force roughly as given by the current from one standard Daniell cell; a better standard is the Hibbert one-volt cell recently introduced. An ohm is the unit of resistance. A 10-feet length of ·01 inch copper wire of 95 per cent. conductivity has roughly one ohm resistance. If we divide the total electro-motive force in volts by the total resistance of the circuit in ohms, we obtain the value or strength of the current in ampères. For measuring ampères, an ampère-meter, or ammeter, is used, and voltmeters are used for measuring the voltage or potential difference between different points of a circuit.

The *Watt* is the electrical unit of power or activity. Just as the rate at which an engine works is measured by horse-power, so the rate of output of a dynamo is measured in watts. Therefore to measure the output of a dynamo in this way multiply the electro-motive force at the terminals of the machine, in volts, by the current in the external circuit, in ampères. Thus, watts equal volts multiplied by ampères. Very nearly, 1 horse-power equals 746 watts.

An *Ampère hour* is a term frequently met with, and means one ampère supplied or required for the space of one hour, or the equivalent. Thus ampères multiplied by hours gives ampère hours. For instance, an accumulator that is said to have a capacity of eighty ampère hours, is one that might give a current of 1 ampère for eighty hours, 2 ampères for forty hours, or 4 ampères for twenty hours and so on.

Armature is a name given to the iron keeper of a permanent magnet. In dynamos it is applied to that part which is rotated within the influence of the field magnets. There are some exceptions, in which the magnets are caused to revolve and the armature is stationary. Revolving armatures and fixed field magnets have the merit of adding stability to the machine and steadiness to its running and the output of the current. Each inventor of a new dynamo appears at first to have adopted a special form of armature; hence we have almost as many forms of armature as there are inventors of machines. The armatures are generally furnished with iron cores, around which insulated copper wires are wound. Machines have been constructed without iron cores, by Messrs. Siemens, Ferranti, Mordey and Thompson. In some of those machines a looped or zigzag band of copper has been attached to a brass spider, mounted on a spindle, and forms the armature. By Lord Kelvin all armatures are divided into four types :—

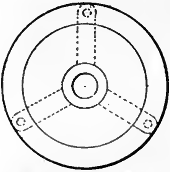


Fig. 6.—Plain Ring Armature.

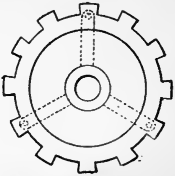


Fig. 7.—Cogged Ring or Pacinotti Armature.

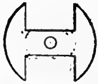


Fig. 8.—Shuttle or H-girder Armature.

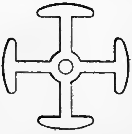


Fig. 9.—Double Shuttle or Walker Armature.

(1) *Ring armatures*, in which the coils are grouped upon a ring whose principal axis of symmetry is also its axis of rotation.

(2) *Drum armatures*, in which the coils are wound longitudinally over the surface of a drum or cylinder.

(3) *Pole armatures*, having coils wound on separate poles projecting radially from a disc or central hub.

(4) *Disc armatures*, in which the coils are flattened against a disc.

Of these it is as well to say that early examples of the first type were furnished by the machines of Gramme, Schuckert, Gülcher, and Brush. Examples of the second type are to be found in the Siemens (Alteneck), Edison, Weston, and Elphinstone-Vincent machines. Examples of the third type were to be seen in the dynamos of Elmore and Lontin. There are but few useful examples of the fourth type, except the Desrosier.

When solid iron is employed for an armature core, eddy currents are set up in the iron, and cause the armature to become hot. Iron armatures should therefore be built up of thin sheet-iron discs, or plates of hoop iron, each layer of iron being magnetically insulated from its neighbour by varnished paper or calico. The armature coils should be of pure copper wire, well insulated with silk or cotton, and the wires should be as short and thick as is consistent with obtaining the requisite electro-motive force without driving the machine at an excessive speed.

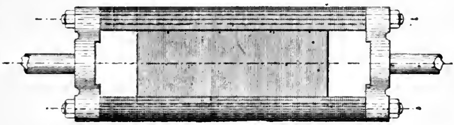


Fig. 10.—Laminated Shuttle Armature.

Figs. 6 to 9 show the types of armatures in use for small dynamos and electric motors. Fig. 6 shows a plain ring armature. It is generally formed of rings or collars of very thin sheet iron. These may be strung together on gun-metal bolts, attached to the arms of brass spiders as shown by the dotted lines, the armature spindle going through the hole in the centre. The rings are wound with several coils of wire, passing through and over the rings. They can also be wound as a drum by winding the coils over the rings only. The drum armature may also be made of discs instead of rings. Fig. 7 shows a cogged ring or Pacinotti armature. This also is made of rings stamped from thin sheet iron, which may be strung on bolts attached to brass spiders. Small armatures are sometimes cast solid in soft malleable iron. The cogs and spaces may vary from six to sixteen, and the number of coils is determined by the number of spaces between the cogs. Fig. 8 shows in section a shuttle or H-girder armature. In small machines this is cast solid. It is also built up of laminated stampings of sheet iron strung on a steel spindle. One coil only can be wound on a shuttle armature. Fig. 9 shows a double shuttle or Walker armature, also built of sheet iron stampings. A coil may be wound on each arm, making four coils in all, or two coils may be wound crosswise. It is not a good armature to wind, as the coils are apt to be of

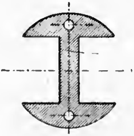


Fig. 11.—Centre Stampings for Laminated Shuttle Armature.

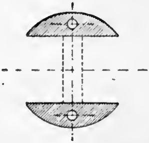


Fig. 12.—End Stampings for Laminated Shuttle Armature.

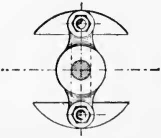


Fig. 13.—End View of Shuttle Armature.

uneven length and resistance. Fig. 10 shows a laminated shuttle armature of a somewhat improved form. The stampings for the centre portion are of the ordinary shuttle or H shape shown in Fig. 11, while the end stampings take the shape shown in Fig. 12. These are strung on two bolts, and clamped together between two castings shown in side elevation by Fig. 10, and in end elevation by Fig. 13. The wire is wound over the central portion or web, and through the spaces at the end, the shaft being driven securely into the end castings.

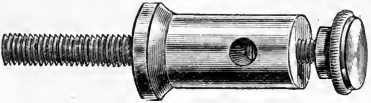


Fig. 14.—Straight Pattern Binding-Post.

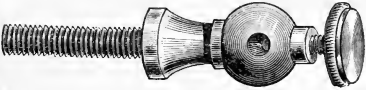


Fig. 15.—Ball Pattern Binding-Post.

Binding-Screws, etc.—These are small clamps made of brass, and cast or turned in various forms to suit requirements. They are sometimes called "connectors" and are used as convenient means of connecting one part of an electric circuit with the rest of the circuit. When made in the form of a pillar or post and fixed by being screwed to a base, they are named "binding-posts." When fixed to the two wires proceeding from a generator of electricity so as to form the two poles of the generator, they are named "terminals." The accompanying illustrations will show at a glance several types of binding-screws.

Fig. 14 shows a binding-post as used for the terminal poles of small dynamo machines. When used for this purpose the post should be massive, the threads on the screws well cut, and the hole for the wire left large. If these posts are nickel-plated, they enhance the appearance of the machine, and require less care to keep them clean. Some makers taper the post from the base upward, whilst others round off the tops. This is merely a matter of taste. The wires from the machine are twined around the tang of the post and secured by a nut beneath the base of the machine. Fig. 15 shows a ball pattern binding-post used for a similar purpose.

Fig. 16.

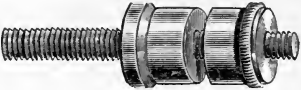
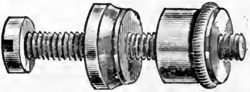


Fig. 17.



Figs. 16 and 17.—Telegraph Pattern Binding-Posts.

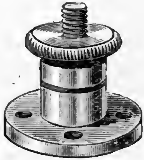


Fig. 18.—Flat Base Terminal.

Figs. 16 and 17 show two "telegraph pattern" binding-posts. These are used for the terminals of telegraph instruments. When made large, they are useful terminals for ammeters and similar instruments. Fig. 18 shows a neat modification of the same terminal; and Fig. 19 shows a similar terminal furnished with a wing nut. This form of nut may be easily screwed and unscrewed without the aid of pliers. It finds favour with French workmen, and is used by them instead of the milled head so commonly met with in binding-screws of English makers. Fig. 20 shows a simple nut and pin terminal, as used to insert in the lead tops of carbons used in Leclanché batteries. Fig. 21 shows one form of wire connector made from brass tube. Two holes are drilled and tapped in the side of the tube to receive two brass screws as shown in the sketch. These connectors are useful when we wish to join a broken wire or connect two wires together. Thick brass tube should be used, or else a lug should be soldered to or cast on the side to thicken it where the screw holes have to be made, otherwise these will not contain enough threads to allow of the screws being securely tightened on the wires.

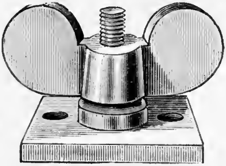


Fig. 19.—Wing Nut Terminal.

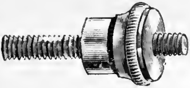


Fig. 20.
Nut and Pin Terminal.

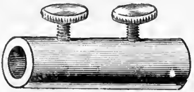


Fig. 21.—Wire Connector.

CHAPTER II.

THE SIEMENS DYNAMO.

In 1857, Dr. Werner Siemens invented the simple form of armature now known as the Siemens H girder, and so called because its cross-section resembles the section of an H iron girder. This is shown at Fig. 8, p. 15. As this form of armature, together with the field magnets, is easily made, wound, and set up, it has become a general favourite. An outline of the machine in general use is shown at Fig. 22, whilst Figs. 23 to 37 show in detail the forms of its several parts. The diagram Fig. 22 shows the position of the parts composing the skeleton, or carcase, of the machine; A being the armature; M, M, the pole pieces; C, C, the field magnet cores; and Y, the yoke to which the field magnet cores are attached by bolts or screws.

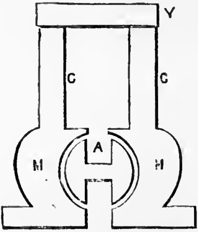


Fig. 22.—Outline of Siemens Dynamo.

The field magnets are often made to the form shown at Fig. 23, or to that shown at Fig. 24, in various sizes, to suit the other parts of the required machine, as shown in the table on p. 24. They are cast in soft iron, and are sent out annealed ready for use. A full set of castings for a Siemens pattern machine of small size can be obtained for about five shillings, and this will make up a 5-candle power machine. The castings for a machine of 120-candle power will cost about thirty-five shillings. All castings received from vendors of these things are in the rough as they come from the foundry, unless otherwise ordered, and an additional price has to be paid for the labour of shaping and fitting them ready for winding on the wire. Supposing, however, that the castings are received in the rough, we will set about preparing the field magnet castings. These should be soft enough to file easily, or they are unsuited for our purpose.

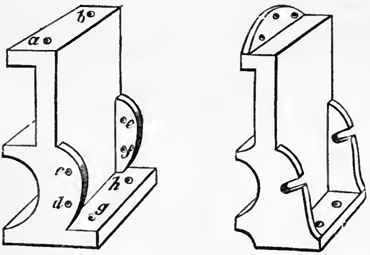


Fig. 23. Fig. 24.

Forms of Field Magnets for Undertype Dynamos.

The first job will be to clean and true up the parts—that is, remove any rough ridges or lumps of iron left on the edges of the armature tunnel. This may be done in a lathe or by means of a half-round coarse file. The two castings for the field magnets must be a pair, and when stood side by side on a level bench, the armature tunnel between them should be of regular form throughout, the cores of one height and size, and parallel with each other when upright. If slight irregularities appear on the sides of the tunnel, take them off with the rounded face of the file. The corners of the cores should also be filed round and smooth, to prevent abrasion of the covering on the wire whilst these are being wound. If the castings are shaped as shown at Fig. 23, holes must be drilled and tapped in the top at *a*, *b*, to receive screwed studs to hold the yoke in its place on the field-magnet cores. Holes about ¼ in. diam. must also be drilled in the lugs at *c*, *d*, *e*, *f*, to receive screwed studs or small bolts securing the armature bearings to the lugs. Two larger holes must also be drilled in the feet of the castings at *g*, *h*, to receive short coach screws used for bolting the castings to their wood base.

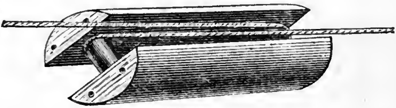


Fig. 25.—Solid H-girder Armature commencing to wind.

The yoke to connect the field magnets, shown at **Y** Fig. 22, is a rectangular piece of iron plate, and must be bedded on the top of the field magnets' cores to hold them in the position In the small Siemens machines supplied by some makers this separate yoke is dispensed with, as the top of one of the castings projects sufficiently to bridge over the space between the two, and thus forms the yoke. In the castings supplied by others, also, the two projections have turned-up flanges, as shown at Fig. 24, and these are bolted together. The two field magnets must be connected in this or in a similar way by an iron bridge, so as to form a horseshoe magnet, between the poles of which the armature will revolve.

The armature of the solid H-girder form used in

TABLE OF SIEMENS PATTERN DYNAMOS.

Size of Cores of Field Magnets. Inches.	*Size of Shuttle Armature.*		*Wire on Field Magnets.*	*Wire on Armature.*	*Output.*			*Revs. per Minute.*
	Length.	Diam.	All connected in shunt.		Amps.	Volts.	C.P.	
$4 \times 1\frac{3}{4} \times \frac{3}{8}$	$1\frac{3}{4} \times \frac{7}{8}$.	Solid.	12 oz. 24, s.c.	$1\frac{1}{2}$ oz. 24, s.c.	1	15	4	3,000
$4 \times 3 \times \frac{1}{2}$	$3\frac{1}{2} \times 1\frac{1}{2}$	Laminated.	4 lbs. 22, d.c.c.	5 oz. 22, d.c.c.	2	25	12	3,000
$5 \times 4 \times \frac{5}{8}$	$4 \times 1\frac{3}{4}$		$4\frac{1}{2}$ lbs. 22, d.c.c.	10 oz. 20, d.c.c.	3	40	30	2,500
$6 \times 4 \times \frac{3}{4}$	$4 \times 2\frac{1}{4}$		8 lbs. 22, d.c.c.	1 lb. 18, d.c.c.	5	45	50	2,000
$10 \times 8 \times 1$	$6 \times 4\frac{1}{2}$		14 lbs. 22, d.c.c.	5 lbs. 14, d.c.c.	7	50	90	1,800

In the above Table the size of the wire is given on the standard wire gauge; "s.c." means silk covered, and "d.c.c." means double cotton-covered copper wire. The candle-power—"c.p."—given is that of incandescent lamps requiring about 4 watts per candle-power, and the machines are designed for this class of lamps.

these machines is shown at Fig. 25. It is a casting of specially soft iron, and is supplied with the other castings for the machine. The channel for the wire should be true and smooth, and the ends of the web should be rounded and smoothed to prevent abrasion of the wire covering. The rounded faces of the cheeks must also be free from lumps, and they must also be true from end to end. The ends must be filed or turned true to form faces for the spindle-holders shown at Figs. 26 to 28. These are secured to the ends of the armature by screwed studs, and holes must be drilled and tapped to receive them.

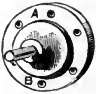


Fig. 26.

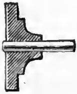


Fig. 27.

Fig. 28.

Fig. 26.—Spindle Holder : End View. Fig. 27.—Section of Spindle Holder. Fig. 28.—Section of Spindle Holder and Commutator.

In larger machines, the armature is built up of punchings of sheet-iron shaped as shown at Fig. 11 (p. 17), or as shown at Fig. 29. These stampings are sold at prices ranging from 3s. 6d. to 10s. per gross, according to size. The stampings are strung on a steel spindle, as shown at Fig. 30, and secured at each end by nuts, so as to pinch the whole series of plates between them. The result is to form a channel for the wire, and faces for the cheeks of the armature, similar to that of the solid H-girder form. This laminated form lessens the tendency of the armature to heat by generating cross currents in itself whilst working. The laminations are separated from each other by varnish or paper, and these help to keep the armature cool. The spindle should be long enough to pass through the end bearings.

The spindle-holders for the solid form of armature are made of brass, either cast with a projecting boss, or made up of a disc of brass with a piece of brass tube fitted in the centre to give holding power on the spindles. The spindles should be of steel, turned true and smooth, and fitted tightly in their respective holders. The projecting bosses of these spindle-holders running against the bearings prevent end shake of the armature ; but when a laminated armature is employed, the ends of the spindle may be turned down a little to form a shoulder for this purpose.

The armature bearings for the smaller sizes of machines, are cast in gun-metal to the form shown at Figs. 31 and 32, or cut from sheet brass to the form shown at Fig. 36 (p. 30), and are secured to the ends of the field magnets by long bolts resting in the slots shown in the lugs, Fig. 24. As the bolts run the whole length of the sides of the machine, they then clamp the front and back bearings together. The bearings for the other forms are similarly made, but they are secured to the lugs of the field magnets by screwed studs, or by small bolts passing through holes drilled in the lugs. Whichever form of bearing is employed, or however it may be secured to the machine, the holes must be exactly in the centre of the armature tunnel, so that the cheeks of the armature may run no nearer to one side than to the other.

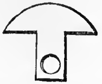


Fig. 29.—Laminated Iron Punching for Shuttle Armature.

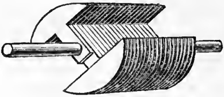


Fig. 30.—Iron Laminations strung on Spindle to form Shuttle Armature.

The field magnets may now be bolted together, the bearings put on, and the running of the armature in its tunnel tested. It should be centred so as to leave about $\frac{1}{20}$ of an inch of space between the cheeks of the armature and the sides of the tunnel. A space the thickness of stout brown paper is enough, but if the space is less than this, the cheeks may bind against the sides of the tunnel. If excessive space is allowed, part of the energy will be lost. If there appears to be a danger of the armature touching the sides at any particular part, mark the place, and ease it with a file. A very effective way to test the running of the armature is to paste a piece of paper over the cheeks, and then revolve it in the tunnel. On taking it out carefully, the abrasions on the paper will mark the prominent parts, and these may then be eased.

This form of armature is wound with only one coil of wire; the commutator will be a "two-part commutator" (*see* Fig. 33)—that is, one divided into two sections, one for each end of the wire coil. These sections must be insulated from each other, and must also be insulated from the rest of the machine. The cheapest and handiest insulating substance available is boxwood well soaked in melted paraffin. Ebonite or vulcanised fibre will also serve the purpose, but these are more costly. Therefore get a chunk of boxwood out of which can be turned a disc 1¼ in. in diameter and about 1 in. thick. Turn this up true, with a hole bored exactly in the centre to fit tightly when driven on one of the spindles. Then get a piece of brass tube 1 inch in length, that exactly fits over the boxwood, and force it tightly on. The smallest sized machines take a commutator ⅞ in. in diameter.

If now this brass-bound boxwood disc were forced on the spindle as shown at Fig. 28, it might work loose in time; so, to prevent it from slipping, turn down the hub of the spindle-holder enough to get a good face for the boxwood boss to fit against, then bore two ⅛ in. holes in the holder, and fit them with two short brass pins. When we have determined how the commutator shall go on the spindle, two shallow holes may be bored in the inside face of the boxwood disc to fit those pins exactly, and so keep it from slipping. The ring of brass must now be divided, and upon the way this is done will depend—all other parts being right—the proper working of the machine. If divided into two equal sections, by sawing straight across the tube, the current from the armature would be interrupted abruptly, and sparks would be caused, which would soon burn away the brass ring and also the brushes. The saw-cut must therefore be made obliquely or diagonally across the ring.

But here we must guard against making the division as shown at A on the left in Fig. 34, for this would be too oblique, and the interruptions would, in consequence, not take place at the proper time. To obtain the proper direction for this saw-cut, turn the disc on one end and draw a line diameterways across the centre, and ⅛ in. on each side of this line draw two other lines. Now scribe two lines on one side of the brass exactly in a line with the two lines on the end. Turn the disc over, and scribe two similar lines across the opposite side. Now on both sides scribe a line across the space between these two lines, from the right-hand end of the top line to the left-hand end of the bottom line. Next, drill and countersink two small holes on each side of the line to receive two very small brass screws, as shown at Fig. 34 (B), and put in the screws, which must not touch the spindle when driven well home. When this has been done, the ring may be divided by sawing it through to the boxwood

Fig. 31.

Fig. 32.

Bearings for Armature. Fig. 31.—End View
Fig. 32.—Section.

on both sides along the diagonal lines, using a hack-saw for the purpose.

The saw-kerf should be widened a little, and cleaned out well with a thin file, or it is apt to get choked and bridged with fine particles of metal worn from the brushes. The holes for the fixing-pins may now be bored, and the commutator fixed in its place on the spindle, having placed it so that the saw-cut in the commutator ring shall be on the side of the coil nearest the left-hand cheek of the armature. Two small holes may now be drilled through the spindle-holder (as shown at A, B, Fig. 26, p. 25). These are bushed with ivory or some other non-conductor, and the ends of the armature coil wire to come through these are securely fastened to the commutator ring.

Fig. 33.—Brass Ring for Commutator.

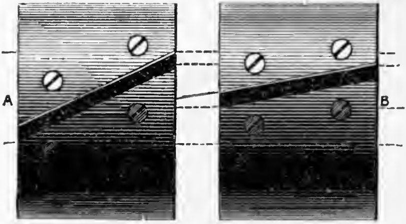


Fig. 34.—Commutator, showing Divided Brass Ring and Screws.

The brushes are long thin pieces of springy brass, copper, or phosphor bronze fixed on each side of the commutator to brush-blocks insulated from the rest of the machine. Their duty is to pick up the impulses of the interrupted armature current from the commutator sections, and convey those impulses to the field magnet coils and to the outer circuit. In the machines of some makers the brushes are attached to boxwood blocks fixed to the bearings of the armature spindle (as shown at Fig. 36); in other machines they are attached to brass pillars screwed into the wooden base of the machine on each side of the commutator. Probably, for small machines, wooden blocks as shown at Fig. 36, with an adjustable brush-holder attached to each block, are the best. With the brushes fixed, as they often are in small machines, their adjustment becomes a tedious task. The brush-holder need be only a small brass bracket with a set-screw, as shown at Fig. 37. The brushes can then be shifted to and fro, and adjusted at any angle required by placing wedges of brass in the clamps above or below the back ends of the brushes.

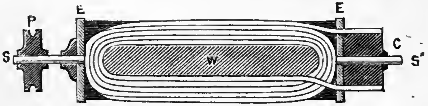


Fig. 35.—Section of Complete Armature.

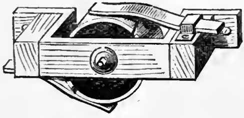


Fig. 36.—Commutator Bearing, showing Position of Brushes.

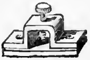


Fig. 37.—Brush Clamp.

A very good material for the brushes of small machines is fine wire gauze cut into strips, and two or three thicknesses soldered to the ends of stout brass springs to ensure proper pressure on the commutator. Three forms of brushes in general use are shown at Figs. 38, 39 and 40. That shown at Fig. 38 is merely a piece of thin spring brass, shaped as shown, and fixed to a pillar brush-holder. This is an objectionable form, as it often gets out of order by wear, and cannot be replaced or adjusted easily. Fig. 39 is an improvement on this form. It is composed of thin sheet brass or hard hammered copper cut to the form shown, with one end slit into fingers to the length of 2 or 2½ in., and a slot cut in the other end to facilitate adjustment. The fingers soon wear away, and must then be replaced. The brush shown in Fig. 40 consists of a piece of hard spring brass, to one end of which is soldered a pad of copper wire gauze. This bears on the commutator, and is kept in contact with it by the strip of spring brass to which it is soldered, the strip being curved as shown at Fig. 36 for this purpose. This pad is most effective as a brush; it does not cut away the commutator like spring brass and copper, and it is easily adjusted or replaced if fixed in a brush-block with clamp, as shown at Fig. 37.


Fig. 38.


Fig. 39.


Fig. 40.

Figs. 38 to 40.—Forms of Commutator Brushes.

The position of brushes for shuttle or H-girder armatures is a matter of considerable importance. It does not matter how the commutator is fixed to the shaft; that point is settled by the most convenient way of holding the brushes. But the rule that must be observed is that—When the two cheeks of the armature are electrically opposite the two pole-pieces of the field, the brushes must rest on the insulating strips on the commutator.

In Fig. 41 this position is shown by the brushes in dotted lines; but in practice the brushes are given a slight "lead"—that is, they are moved forward through a small angle in the direction in which the commutator moves. This brings the brushes on the insulating strips, not when the cheeks of the armature exactly face the pole-pieces, but just a little after they have passed the centre line.

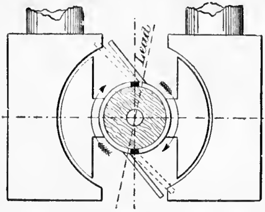


Fig. 41.—Position of Brushes for Shuttle Armature.

The brushes with this lead are shown in Fig. 41 in full black lines, with a centre line showing the angle through which they have been turned. The exact amount of this lead can only be found when the machine is at work, for some armatures require more than others; for instance, a rather hard solid shuttle armature may require more lead than one built up of separate punchings. The brushes should have just enough lead for the machine to give its full current without sparking. Just a trifle too much or too little lead may easily bring about sparks, which not only mean waste of power, but also eat away both brushes and commutator, and should therefore be avoided.

Before winding the armature, see that the channel is free from lumps, and the ends of the web are smooth

Then cut a strip of silk large enough to envelop the web, and coat this with good shellac varnish. Lay the silk evenly to form a bed for the wire, and varnish the silk and the channel, and when the varnish is dry proceed to wind on the wire. This will be all the better for the purpose in hand if it has been previously soaked in hot melted paraffin. Commence winding as shown at Fig. 25, p. 23, lay each coil evenly, as a reel of cotton is wound, and wind close and tight, until the required amount of wire has been wound on. The wire coil must not stand above the cheeks of the armature. If a stray layer stands up above the others, and threatens to knock against the sides of the field magnet tunnel whilst being revolved, it must be pressed into its place with a piece of smooth wood. Then bring the two free ends to one end of the armature, put on the spindle-holder (Fig. 26, p. 25), bring the ends through the ivory-bushed holes A and B made for this purpose, put on the commutator, and solder the two ends of the coil to the two sections of the commutator. Then put on the other spindle-holder, and the armature is complete. Fig. 35, p. 30, shows a section of the armature thus finished. It is lettered as follows:—W, web of armature; E, spindle-holders; C, commutator; S S, shaft or spindle; and P, driving pulley.

Whilst winding the wire on the armature or the field magnets of a dynamo, great care must be exercised to get each coil of wire close to its neighbour, and each layer of wire regular and close to the layer beneath, for on this will depend the full efficiency of the machine. Slack and irregular winding will cause loss of power, and this is specially observable in the winding of the armature, where cross winding will not only prevent a maximum number of coils being got in a given space, but will also cause cross currents in the wires. Nevertheless, whilst giving all attention to the tightness and snugness of the winding, it is possible to be too zealous in this direction, and fall into the more serious error of pulling the wire so tightly over the iron ends of the armature as to cause the iron to cut into the covering of the wire. One such abrasion of the covering, however small, will render the machine useless, as electrical contact will be made through the iron of the machine as well as through its wire coils.

Such accidents as these are of frequent occurrence, and to detect them it is necessary to have a small galvanometer, or current detector, and with it to test the insulation of the covering as the winding proceeds. Almost any price may be paid for a galvanometer, from 2s. 6d. up to £10, according to the value of material and workmanship in the instrument; but a plain and simply constructed one, good enough for this purpose, can be got for 10s., or perhaps less. To test the wire for complete insulation whilst winding, connect a free end of it to one stud of the galvanometer; connect the other stud to one terminal of a good battery (one cell of a Bunsen or a bichromate will do very well), and attach a length of copper wire to the other terminal of the battery. With the end of this wire touch the bare iron of any part of the armature (or of the field magnets whilst winding them). If the needle of the galvanometer is deflected, it may be taken for granted that the wire covering is abraded, and each coil must be unwound until the faulty place is discovered. Such faults are best repaired with a thread of unspun silk or soft darning-cotton, soaked in melted paraffin and wound around the abraded spot. If the galvanometer needle does not move at all when the iron is touched with the battery wire, we may be fairly certain that the coil is insulated from the iron of the field magnet core, or of the armature, as the case may be.

Greater care is needed in winding a laminated armature than in one having a solid core, since the edges of the end plates are liable to cut through the protecting coat of silk and covering of the wire if this is pulled too tightly over the edges. Some little difficulty also will be experienced in getting the coils of wire to lie close to the spindle whilst winding them on one side. This may be overcome by tying each coil back with a short piece of tape, until the curvature of the spindle has been passed. In winding a laminated H-girder armature for a Manchester field, the coils may be prevented from slipping at the ends by bending forward two of the laminated plates at each end, so as to form two flanges, against which the coils can rest as against the sides of the end slot in a solid armature. As there are no spindle-holders through which to pass the ends of the coil we have to fasten them direct to the sections of the commutator, to the inside edges of which they should be secured by solder. It will also be advisable to tie the ends down to the spindle with a few turns of tape, to prevent the outer coil from shaking loose in working.

Before winding the field magnet cores, it will be necessary to prepare them for the wire by wrapping around them a layer of silk ribbon well soaked in melted paraffin, applied to the iron warm, and then made quite smooth. The wire should also be prepared for winding by first dividing the allotted quantity into two equal parts, making these into hanks or coils large enough to go loosely over a two-gallon stoneware jar, and then well soaking them in melted paraffin. The wire for the dynamos specified in the table on p. 24 may be divided by measurement, if it is found inconvenient to divide it by weight, if we remember that No. 22 S.W.G. d.c.c. copper wire measures 125 yards in the lb. The wire may be wound on by hand if the worker is unprovided with suitable apparatus, but it can be wound more regularly, smoother, and tighter in a lathe, or by means of a special winder, which can be easily and cheaply made up for the purpose from a few scraps of wood, a few bolts, and a winch-handle. Centre the field magnet casting in the lathe, and when it runs true, proceed to wind on the wire.

If the hank of wire has been placed over a glazed stoneware bottle filled with water, the coils will slip off easily as the wire is wound on the casting. Commence at the channel or bottom end of the core; wind some seven or eight inches of the wire on a pencil to form a close spiral, to be stretched out after winding to form connections. Lay this close to the bottom end, take one turn around the casting, and secure the spiral to this turn with a piece of strong twine. Wind on the coils evenly side by side, and when within two inches of the end, lay in two four-inch lengths of tape under the last few coils on the outside of the core, leaving the ends hanging. Before winding back with the next layer, bring the ends down over the first layer, and thus secure the last few coils of the first layer from slipping away under the pressure of the next. If the ends of each layer are thus bound, there will be no danger of the top layer sinking in between the coils of that beneath it.

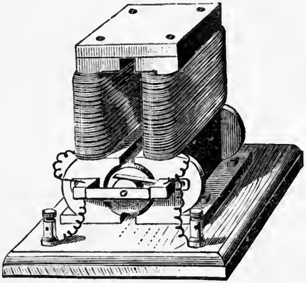


Fig. 42.—Siemens-type Dynamo complete.

When all the wire has been wound on, tie the free end to one of the coils, or to the core, with a piece of stout twine. Serve the other field magnet core in a similar manner, testing each layer for insulation as the work proceeds ; then coat the outer wires with a layer of sealing-wax varnish, and set them aside to dry. As the cores of some forms of field magnets are unprovided with flanges, this method of taping just described will be found very convenient in preventing slipping of the end coils; but flanges are preferable where these can be introduced, as they not only prevent slipping but also protect the coils from possible injury.

The various parts having been prepared, they must now be fitted together. It is well known that a straight bar magnet has two opposite poles—one at each end. One of these is called the north pole of the magnet, its opposite being the south pole. If now we bend the bar in the shape of a horse-shoe, the two poles are brought near each other, but they still preserve their characteristic opposite polarities.

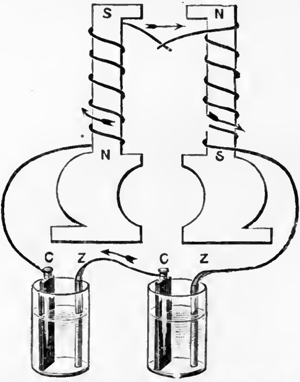


Fig. 43.—Magnetising Field Magnets.

If we wind an insulated copper wire around a straight bar of steel or of iron as in the left half of Fig. 43, and send an electric current in the direction of the arrow, through the wire, we shall find that the lower end N of the iron or steel bar has assumed a north magnetic polarity, and at the same time its opposite end S has a south magnetic polarity. If an iron bar be bent into the shape of a horse-shoe with the wire on, it will then resemble the two field magnets of Fig. 43, with space between the legs in which the armature may revolve. The two field magnets are wanted, with a north pole on one side of the armature and a south pole on the other side. As both of the cores have been wound from the bottom or channel end, it follows that if we send a current through each separately in the same direction in which they are wound, the two bottom cheeks would be both north poles, and if we connected the finishing end of one coil of wire with the commencing end of the other, we should realise the same result; but if we connect together the two finish ends of the coils, as shown at Fig. 43, and send a current from the left-hand end to the right, it will enter at N, traverse the coils in the direction shown by the arrow, leave at S, cross over to the right-hand core, and traverse its coils in the opposite direction, thus producing a south pole at the bottom and a north pole at the top.

Connect one or two quart Bunsen or bichromate cells to the coils, taking care to join the carbon of the battery with N on the left, and the zinc of the battery with S on the right. As the current in a battery may be supposed to start from the zinc and move through the liquid towards the other element, we can by this means always ensure sending a current in the right direction. When thus magnetised, the field magnets may be connected together and the machine fitted together.

The field magnets are fastened securely together by the yoke at the top, but to ensure proper rigidity and stability to the machine, they must also be firmly secured to a thick, well-seasoned board of oak, teak, walnut, or mahogany by short coach screws passing through the lower outstanding flanges. This board may be trimmed at the edges, planed, and polished, to ensure a finished appearance. The complete machine is illustrated at Fig. 42, p. 36.

From the simplicity of its design, this type of machine lends itself readily to illustrate how the wires of a dynamo should be connected. Figs. 44 and 45 show two distinct methods of connecting the wires. The method shown by the full lines at Fig. 44 is called connecting as a series machine—that is, the field magnets, the armature, and the outer circuit may be regarded as three cells of a battery, and the whole connected up one after the other in one circuit. No current can pass through the field magnet coils until the outer circuit is completed. When one end of the field magnet wires is connected to the brush A, and the other end to the brush B, as shown by dotted lines in the diagram Fig. 44, the machine will be short-

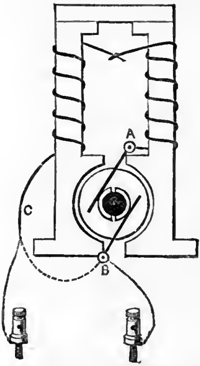


Fig. 44.—Diagram of Series Connections.

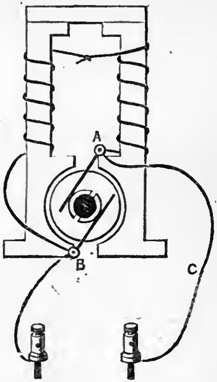


Fig. 45.—Diagram of Shunt Connections.

circuited. But if we break one of the wires at C, and take it to a binding-screw, then take the piece hanging to B, and connect that to another binding-screw as shown by the full lines, the two screws will form the two poles of the machine, to which the wires from the outer or working circuit must be attached. This method of connecting the wires is only suitable in special cases, as for working arc lamps.

Fig. 45 shows a method of connecting the machine in shunt—that is, only part of the current generated in the machine passes through the coils of the field magnets. The ends of the coils are then connected with the two brushes, and these are both connected with the binding-screws which form the terminal poles of the machine. The circuit is now divided, part of the current going through the work in the outer circuit, and part going through the field magnet coils. This is the method of connecting occasionally adopted in dynamos intended for running incandescent electric lamps, because the electro motive force generated is, within certain limits, kept constant. Compound winding, a combination of the series and shunt, is, however, better suited to this purpose. The letter references in this Fig. correspond to those in Fig. 44.

CHAPTER III.

THE GRAMME DYNAMO.

In 1871 a French electrician named Gramme invented a dynamo in which he used as the armature a ring of soft iron wires with insulated copper wire wound in sections over it. Although he was not the first to use a ring armature made of iron, he was able to patent this modification, which gave birth to the form of armature since modified and altered in many different ways, but still known as the Gramme ring. The patent expired in 1884.

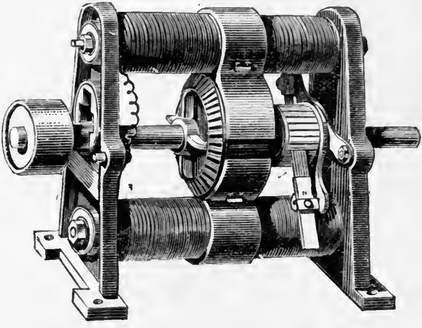


Fig. 46.—Gramme Dynamo Complete.

The many modifications of Gramme's iron ring, including the Gramme ring itself, must, however, be regarded as developments of a discovery made in 1860 by Dr. Antonio Pacinotti, Professor at the University of

Pisa, who found that he could make a most efficient dynamo by employing as an armature an iron wheel with sixteen cogs, and winding between the cogs sixteen coils of insulated copper wire. Here, then, was the first ring armature.

Some idea of the general appearance of a Gramme dynamo will be gathered from Fig. 46, which represents a small Gramme machine complete.

The carcase of the Gramme dynamo differs in form and structure from that of others. A general idea of it is given in Fig. 47, where s, s, represent the iron standards or supports; c, c, c, c, the field magnet cores without flanges; and m, m, the pole pieces between which the armature revolves. Soft iron castings can be cheaply obtained, and as probably they will be received rough as they come from the foundry, they must be put into shape and fitted for use by the dynamo maker himself. The first thing to be considered and taken in hand will be the standards, one of which is shown at Fig. 48, fitted with a bridge for the brush-holders. It will be seen, on referring to Fig. 47, that each standard has two projecting lugs, one on each side. The uses of these are: in

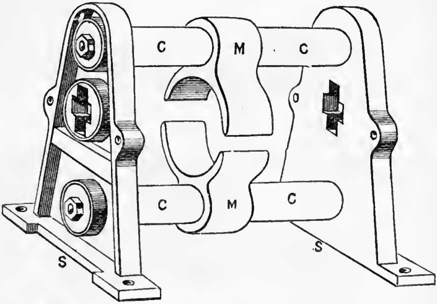


Fig. 47.—Iron Carcase of Gramme Dynamo.

one standard to hold the bolts which support the bridge of the brush-holders, and in the other standard to hold the terminals of the machine. The bridge for the brush-rocker bearing may be one of the iron castings sent with the carcase. This must be mounted on the face-plate of a lathe, the boss bored to allow the spindle to pass through, and turned on the outside to hold the rocker of the brush-holder. In Fig. 48, the holes F, F, above and below the bridge (marked R) are for the bolts of the field magnet cores to pass through. It is essential that the flanged ends of the cores should be in perfect magnetic contact with the iron of the standards, so it will be advisable to surface the rough iron within the diameter of the core flanges shown in Fig. 49, to form bearing surfaces for the bright ends of the turned core flanges. The other standard must now be treated in a similar manner, but in this the holes in the lugs will be plugged with ebonite, to hold the terminals. Holes must be bored in the feet of the standards, to receive bolts for fastening the machine to a bench or to the floor. The cross-shaped slots in each standard are intended to

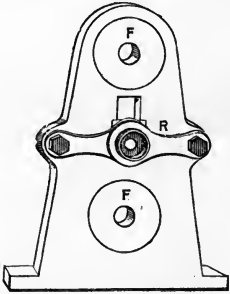


Fig. 48.—Inner Face of Standard with Bridge for Brush-Holders.

hold the brass bearings, which are fitted into the lower portion of the slot, and held in position by small wedges.

The field magnet cores (Fig. 49) are best cast in one with the cheeks, or pole pieces, and the flanges, and with a wrought-iron bolt embedded at each end of the casting with the threaded part projecting as shown. Perfect contact is then ensured between all the parts, and this is important in order to maintain magnetic continuity between the pole pieces and the standards which form their yokes. The outside faces of the flanges should be turned true and bright, to ensure a clean surface contact. Both cores with their pole pieces may now be fitted to the standards, the ends of the projecting pins screwed and fitted with nuts, and the cheeks made to hang in line with each other. Then bolt the cores and standards up tight, mark by small nicks with a file on flanges and standard the positions of each piece, and drill on each side of the core through each flange $\frac{3}{8}$-in holes into the standards to the depth of $\frac{1}{4}$ in. Iron pins fitted in these holes and fixed in the flanges, will form a guide in fitting the parts together after the cores are wound with wire, and ensure that the cores shall be placed in their right position.

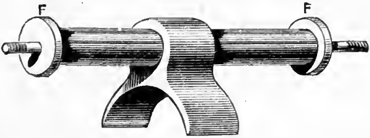


Fig. 49.—Magnet Core with Flanges and Pole Pieces.

The armatures of small Gramme machines are not now made of iron wire, as in the original machines. They are now built up of rings of sheet-iron, shaped as shown at Fig. 50, with a number of cogs on the periphery of each ring. It will thus be seen that the armature is practically a Pacinotti ring armature. The number of cogs and intermediary spaces are arranged on each machine to suit the designer, and may be any even number, such as ten, twelve, fourteen, sixteen, and so on. In the small machine shown, the number is ten, and the laminations range in thickness from fourteen to twenty-five to the inch. The method of building up is as follows: small holes are drilled through alternate cogs of each lamination, as shown at Fig. 50.

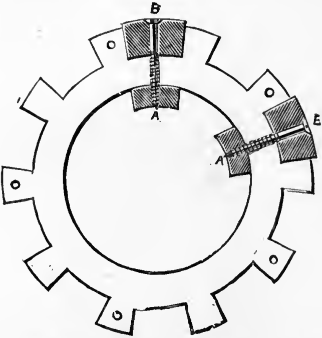


Fig. 50.—Laminated Iron Punching for Ring Armature.

These holes may be $\frac{1}{4}$ in. or $\frac{3}{8}$ in. in diameter, but they must exactly coincide with each other through the whole number of plates, as they have to admit rods on which the laminated plates are strung. The rods should be of a material of high electrical resistance, to avoid eddy currents in the armature when at work. Both ends of each rod may be threaded, and fitted with suitable hexagonal nuts. Ebonite bushes and washers should be placed between the nuts and the armature spiders and plates.

The plates may next be coated with good tough varnish, such as Japan or Brunswick black, and set aside until the varnish is dry and firm. They are then strung on the rods, and all bolted securely together to form one continuous wide ring. This ring must now be mounted on a support, which in turn has to be fixed to the spindle, whilst space must be left between them for winding the coils of wire. This support, or spider, may be of brass or of gun-metal, and is generally sold with the other castings. One with five spokes, to suit a ten-cogged

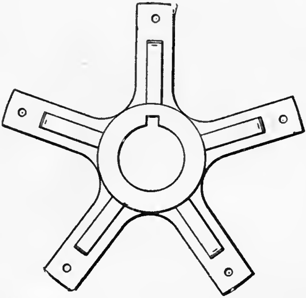


Fig. 51.—Spider for Laminated Ring Armature.

armature, is shown at Fig. 51. Each arm must have a hole drilled in it as shown, to fit the ends of the rods running through the armature plates. The hole in the centre must also be bored true to fit the spindle, and a key-way cut as shown. When bolting these spiders to the armature, care should be taken to tighten all the nuts gradually, and so bring the plates and spiders together without straining the threads. This done, the surplus thread should be cut off, the ends of the rods rounded, and each nut secured with a touch of soft solder.

In preparing the armature each space between the cogs will be filled with a coil of wire, wound by passing one end of it through the space between the arms of the supporting spider and around the combined thickness of the laminations, as shown at Fig. 52. As the space inside is slightly less than that between the cogs there is a danger of the inner part of one coil encroaching on the wire space of its neighbour. To prevent this, wooden guides may be employed, fixed between the cogs on the outside, and secured to other wooden guides inside the armature by suitable screws passing through the ends, as shown at Fig. 52, and also in section at A B, A B, Fig. 50. These effectually prevent slipping of the wire coils whilst the wire is being wound on, and can be moved from one space to another as the work proceeds.

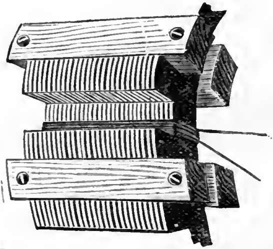


Fig. 52.—Portion of Ring Armature ready for Winding.

Before preparing the spindle for the armature, it will be advisable to fit the bearings in their places in the standards. These should be fitted in the lower part of the crosses in the standards; the cross-slit receives an iron plate, fixed in with wedges, to hold the bearings down, and the upper part of the cross forms a space for the lubricator. The stem of this lubricator is screwed to fit a hole in the wedge-plate, and the oil is conducted through a hole in the upper half of the bearings, which are turned true, and fixed securely.

The spindle should be made of mild steel, of a size and length suitable to the machine in hand, and turned to the shape shown at Fig. 53. The left-hand end from A to B will run in the left-hand bearing of the machine, shown at Fig. 46 (p. 41), and carry the driving-pulley. The two shoulders at B and C are for the bearing and the boss of the armature spider respectively: At D and E holes must be drilled through the shaft and fitted with pins, which project and fit the key-ways left in the spiders, and thus prevent the armature from turning round on the spindle. The space between E and the screwed part at S will be occupied by the commutator; the remainder of the spindle will run in the right-hand bearing, Fig. 46.

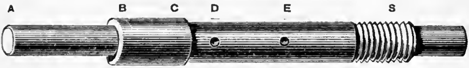


Fig. 53.—Armature Spindle of Gramme Armature.

A hexagonal nut must be fitted on the thread at S to bring the commutator and the spiders of the armature in close contact with each other. The spindle being prepared, next mount the armature on it, put the spindle into its place, and spin it round to see that every part runs true, as now will be the time to make any alteration required. This done, with a half-inch square file trim off any roughness which may appear on or between the armature cogs, so as to make the whole smooth. If the cogs do not properly clear the pole-pieces, the projecting parts may be trimmed off in a lathe. The spaces between the cogs should now be coated with varnish and the armature set aside to dry, preparatory to being wound with wire.

The commutator is furnished with several segments, corresponding in number with the coils on the armature. Fig. 54 gives a general idea of its appearance when finished, whilst Figs. 55 and 56 show how it is constructed. In the centre of a piece of well-seasoned boxwood, large enough to turn out a solid hub of not less than 2 in. in length and 3 in. in diameter, bore a hole to fit the armature spindle. On this cylinder of boxwood mount the bars of the commutator, as shown in Fig. 54. It would be possible to cut out these bars one by one from a sheet of hard brass, and fit each to the outside of the cylinder; but the commutators of small dynamos may be built up by a more convenient and accurate method. Procure a piece of gun-metal tube, with sides quite ¼ in. thick, and of a diameter large enough to fit over the box-wood hub, after a light boring cut has been taken through the

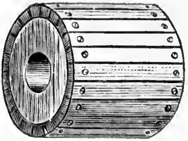


Fig. 54.—Commutator for Ring Armature complete.

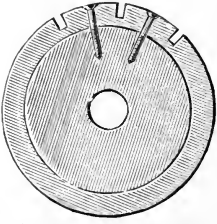


Fig. 55.—How to divide Commutator Ring.

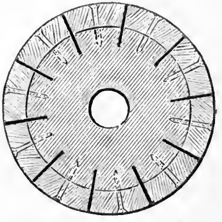


Fig. 56.—How to insulate Commutator Segments.

inside to render it smooth. Cut off a piece of the tube long enough to cover the hub, and fit it tightly on. Now divide the ring into as many equal-sized sections as there are cogs on the armature. If there are ten cogs have ten sections, if fourteen cogs have fourteen sections, but each section must be equal, so as to form a series of equal-sized bars all round the hub. The division lines should be deeply marked with a sharp steel scriber, and then nicked with a hack-saw, as shown at Fig. 55. Next drill a small hole through each end of each section and into the hub beneath ; countersink the mouth of each hole, and drive a short brass screw into each, as shown in Fig. 55. This done all round, with a saw separate each section from its neighbour, and allow the saw to enter the boxwood hub to the depth of nearly ¼ in., to form a hold for the insulating substance to be placed between each section. The insulating substance may be either vulcanised fibre or asbestos millboard. Procure some sheet fibre or millboard, a trifle thicker than the saw-cut divisions, and from it cut slips large enough to fill the cuts exactly, as shown by the thick black lines at Fig. 56.

Slightly ease the screws of each section, wedge the prepared insulating strips firmly into each saw-cut, then tighten the screws again, and so pinch each strip tightly on each side between the edges of the sections. When this is done, mount the hub in a lathe, and true up all rough projecting parts with a sharp tool, or with a rough file at first and then with a smoother file.

Each segment of the commutator will have to be connected to the ends of two coils of wire, and the best means of making a connection is in the following manner :—Choose either end of the commutator to go next the armature, and in the extreme end of each section drill a $\frac{1}{16}$ in. hole, and tap each hole to receive a screw. Next take a length of No. 12 S.W.G. hard copper wire, and cut it up into two-inch lengths. Flatten one end of each length as shown at Fig. 57, and screw the other ends to go into the tapped holes made to receive them.

Tin the screwed ends of each connector with solder, and as they are done screw them into their places, giving each a touch with the soldering-bit to make the solder run, and fix the connector firmly in its place.

A disc of vulcanised fibre, slightly larger in diameter than the commutator, should now be turned out of a piece of ¼-in. sheet fibre. This must be placed between the end of the commutator and the arms of the armature spider, to ensure the complete insulation of the one from the other when they are tightened up on the spindle.

Before winding the wire on the armature, calculate how much will be needed for all the coils, and divide this quantity equally among them, to ensure each coil having the same resistance. A table at the end of this chapter gives particulars suitable to each size of armature. In this table only three sizes are specified: namely, Nos. 16, 20, and 22 S.W.G. By remembering that No. 16 cotton-covered copper wire runs about 25 yards in the lb., No. 20 runs 80 yards in the lb., and No. 22 runs 120 yards in the lb., we can easily calculate the length of wire for each coil by multiplying the number of yards per lb. by the number of lbs. to be used, and dividing this by the number of coils to be placed on the armature. For instance, supposing we have to use 4 lbs. of No. 20 S.W.G. on an armature with 10 divisions:—4 × 80 = 320; and this, divided by 10 (the number of divisions), will give 32 yards to each division. Measure off the length for each coil, and roll the wire up into hanks, containing one coil in each hank. Place each hank in a vessel containing hot melted paraffin, and let it soak for several minutes, then hang it up to drain dry.

Fig. 57.—Copper Connector for Ends of Armature Coils.

Next make a shuttle of tough hard wood, to the shape shown at Fig. 58. This shuttle may be 9 in. in length, and of a width suitable to the size of the spaces through which it has to pass; the gaps in the ends must also be cut large enough to take the whole coil of wire, and this will vary with the size of the armature to be wound. The shuttle for the smallest on the list (on page 59) should measure 9 in. × 1 in. × ⅛ in., and should have gaps ¾ in. deep by ⅝ in. in width. All edges must be rounded and made quite smooth, to prevent chafing of the cotton or silk covering whilst winding the coil. This shuttle must now be neatly wound with one of the coils of wire, and then we are ready for transferring it to the armature.

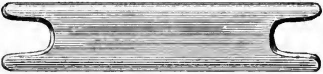


Fig. 58.—Wooden Shuttle for winding Armatures.

This is a two-handed job, and it is necessary to have a helper whilst doing it. The armature ring may be held on a low trestle between the winder and his assistant. Examine the edges of the spaces between the cogs and inside the ring, to detect any rough places likely to abrade the wire covering. If any of these appear, do not file them down—for in so doing the dried coat of shellac varnish would be injured—but cover them with short pieces of broad tape, stuck on after being well soaked in hot paraffin wax.

Begin winding on the left-hand side of one of the spaces, next to an arm of the spider. Wrap a few turns of the outside end of the wire around the arm of the spider, just to hold it in its place, pass the shuttle to the assistant over the armature, and get him to pass it back through the ring; lay the coil up close to the left-hand cog, and draw it moderately tight; then pass the shuttle over again to the assistant, who will return it through as before (*see* Fig. 52). Thus proceed, laying each coil close against the one preceding it, until the space between the two cogs has been covered by one layer. Then wind back from right to left until this layer has been closely and regularly covered with another layer. If using large wire, such as No. 20 or No. 16, there will be a tendency on the part of each coil to bulge in the centre of the space. This bulging must be kept down from the start by gently tapping the bulging part (whilst tightening the coil) with a small wooden mallet, or by placing a piece of wood on the wire, and striking the wood with a hammer. The wire must be kept level and compact in the outside space, but in the inside this may be disregarded. Whilst winding the coil test it frequently for insulation, and make good each fault before going on further, for leakage here will destroy the efficiency of the machine. When the first coil has been wound, leaving the wire ending on the side of the space opposite to that where it commenced, and with enough projecting to reach the commutator, fasten down the wire and coat the outside of the coil with some quick-drying varnish. Remove the guiding pieces of wood (shown in Fig. 52, p. 47), and coat the inside coils with varnish in a similar manner. This will help to fix the wire in its proper position, and also secure better insulation of one coil from its neighbour. The whole wire should now receive one or two coats of varnish, the commencing end of each coil being also painted with a distinctive colour to facilitate its recognition when connecting the ends to the commutator bars.

When the varnish is dry and hard, the armature may be mounted on the spindle. The commutator must be forced on tight in its place, and fixed close to the fibre washer by screwing up the nuts on the threaded end of the spindle. It is well to have two nuts, one to lock the other and prevent the parts from shaking loose. The coils may now be connected to the commutator bars by soldering the commencing end of one coil and the finishing end of its neighbour to its connector, as shown at Fig. 59. It will be found convenient to bare the ends of the wires and clean them, then to twist the end of one coil round the commencement of another, so as to form a clip on each side of the connector, and then to tin this twisted part with the soldering-bit before soldering to the connector.

When a small armature is tightly wound with a coil of fine wire covered with some two or three coats of varnish, the whole should hold well together. But there is always a danger of disruption, owing to the immense centrifugal stress, when whirled round at from 2,000 to 3,000 revolutions per minute, and a wire thrown out would entail disastrous consequences when the coils revolve close to the pole-pieces. It will be well, therefore, to bind the middle of the armature coils with several coils of tarred tape, so as to form a hoop, and to wind tightly over this a length of No. 24 s.w.g. phosphor-bronze wire, laid evenly side by side, for a distance of about a ½ in. in width. The ends of the wire must be twisted together and soldered, using resin only as a flux; and it will also be advisable to solder

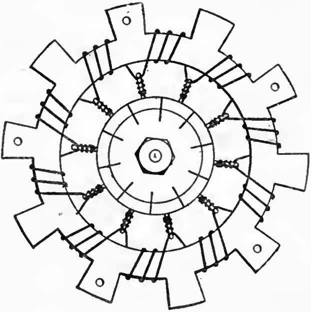


Fig. 59.—Connection of Armature Coils to Commutator.

the whole layer of wires together here and there, where they pass over the cogs of the armature.

The brush-holders and brushes for this type of machine are not fixed to the bearings or to the pillars, as is done in the small Siemens machine; they are made in the form of a rocker, pivoted on a bridge attached to one of the standards, as shown at Fig. 48 (p. 43), and are therefore free to be moved round the commutator as desired. The rocker is often an iron casting, shaped as shown at Fig. 60. The large hole in the centre is turned to fit loosely on the boss of the bridge shown at Fig. 48. A hole is drilled and tapped in the crown, as shown at C, Fig. 60, to receive a set-screw which is used to fix the rocker in any required position. Two ½ in. holes, B, B, are drilled through the rocker, these holes are plugged with ebonite, and through each plug a ¼ in. hole is drilled to receive the screwed ends of the brass spindles, S, S, which carry the brush clamps, C, Fig. 61. The spindles may be made of ⅜ in. brass rod, and the outer ends should come within ¼ in. of the inner edge of the commutator. The inner ends must be turned down to go through the ebonite plugs in the rocker, and screwed to take a hexagonal nut on each side of the rocker, as shown at A, A, Fig. 61. These nuts must be insulated from the rocker by washers of ebonite or of vulcanised fibre. The opposite ends of the spindles must be fitted with two more hexagonal nuts to hold the brush clamps; these are of gun-metal, shaped as shown in Fig. 62. The

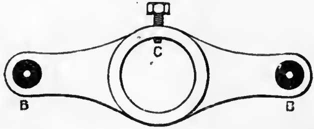


Fig. 60.—Rocker for Brush-Holder.

upper part of this clamp is formed to receive the brushes, which are made of strips of hard brass, copper gauze, phosphor bronze, or whatever material may be chosen. The strips are held by a brass plate placed on top of them, and secured by the thumb-screw *d*. Holes are bored in the lower part, as shown at *e*, *e*, for the spindle to pass through. The clamp being thus free to move around the spindle, together with the movement of the rocker, allows the brushes to be adjusted to any required angle. A small brass staple soldered to the inside of each clamp receives the end of a spiral spring threaded on the spindle, and this ensures due pressure of the brushes on the commutator, whilst it also keeps the clamp in its proper position at the end of the spindle. In adjusting the brushes it is found advisable to move the rocker by means of an insulated handle made of ebonite or vulcanite, as shown at one end in Fig. 61. The handle may be attached by screwing it on a short stud

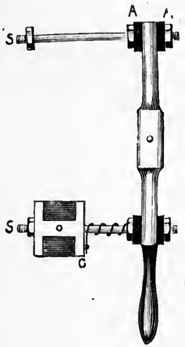


Fig. 61.—Brush-holder and Rocker complete.

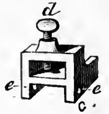


Fig. 62.—Clamp for holding Brushes.

fixed in the end of the rocker. A similar handle may be fixed at the other end if desired.

In the field magnets of a Gramme machine the wire will be wound in four separate coils, so it will be advisable to divide the total quantity of wire to be used into four equal parts, and to treat each part as recommended in the case of the wire for the armature.

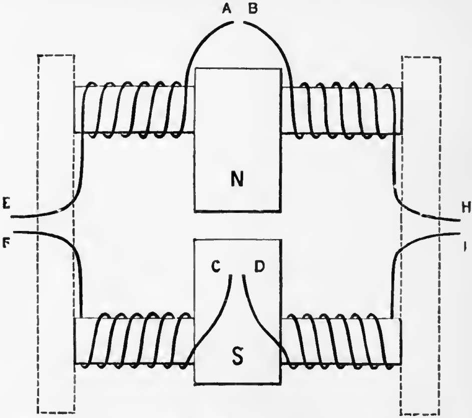


Fig. 63.—Winding Field Magnets of Gramme Dynamo.

After each coil of wire has been soaked in paraffin-wax, it should be wound on a stout wooden bobbin, as it will run off more easily from a bobbin than from a hank. The method of winding so as to secure a north pole piece above the armature and a south pole piece below the armature is shown at Fig. 63.

Mount the core to be wound in a lathe geared to slow speed. Twist one end of the wire A round the core, cross it over the pole piece, take one turn round its own core, and tie this turn with a short piece of twine. Then proceed to wind on the wire evenly and regularly, with the coils close side by side, from the pole piece on the right to the end of the core at the left, to and fro, until all the wire has been wound on; then tie the last coils together tightly with a piece of narrow tape to prevent them from springing loose when the end E is free. Next unfasten A from the right-hand core, and commence winding on the next coil, beginning at B and winding from left to right, observing the same precautions as in the first coil, finishing off the opposite end at H. Next, wind the cores for the lower pole piece, commencing each at C and D respectively, and finishing off at F and I. If the fields are to be connected in series, the two ends E and F will now be led to the two terminal binding-screws, and the two ends H and I to the two brushes; whilst A will be coupled to B, and C to D by screw connectors, as shown by full lines in Fig. 64. If the fields are to be connected in shunt, the two ends E and F will be connected together to form

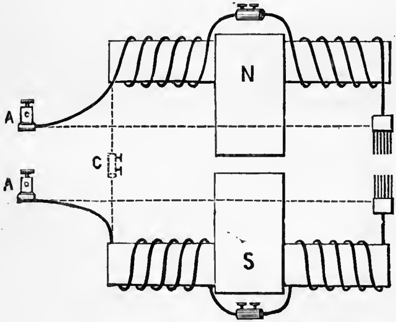


Fig. 64.—Connecting Fields in Series and in Shunt.

a continuous coil from H to I. These two ends only will be connected to the brushes, and from the brushes two short pieces of wire will go to each terminal. The dotted lines in Fig. 64 show this more clearly. When the two finishing ends of the left-hand coils are connected to the two terminals A, A, and the two finishing ends of the right-hand coils are connected to the brushes B, B, the circuit can only be completed through the external circuit in series with the coils and joining the terminals. But when the two ends of the left-hand coils are coupled direct, as shown at C, and the brushes are connected with the terminals, as shown by the dotted lines, the current is shunted through the coils, and when the machine is running the cores are always magnetised. The cores must be charged with initial magnetism, given by a battery sending a current through the coils, as explained on page 38.

The dimensions of the various parts have not been mentioned in the general instructions which are applicable to several sizes of machines. All parts are, however, made proportionate to the size of the castings, and the vendor of these will also supply the various parts in the rough at a less cost than would be incurred by making patterns and having the parts cast to order. The following list of Gramme machines gives the dimensions of various parts and the output to be obtained.

TABLE OF GRAMME DYNAMOS.

No	*Cores. Inches.*	*Cogged Armature. Inches.*	*Double cotton covered Wire on Field Magnets.*		*Wire on Armature.*		*Revs. per Minute.*	*Power Developed.*		
		Diam. Depth.	Lbs.	s.w.g.	Lbs.	s.w.g.		C. P.	Ams.	Vlts.
1	1⅛ × 2	3½ × 2	6	22	1½	22	2,500	30	3	40
2	2 × 3¼	4⅞ × 2½	10	22	4	20	2,000	65	5	50
3	3 × 6	6 × 6	20	20	4	16	1,500	150	10	55
4	4 × 7	7 × 10	90	16	12	16	1,200	450	30	55

The various parts of the machine may now be assembled. The field magnet coils should have two or three coats of varnish to cement the wire together, and to give the whole a finished appearance. In adjusting the brushes, move the rocker until by actual trial the best position is found. This position is indicated when with a full current at the terminals there is very little noise at the brushes, and little or no sparking where the brushes touch the bars of the commutator.

Machine No. 1 has a solid cogged armature; all the others are built up of cogged laminated plates. The armature of No. 4 has two strands of No. 16, used side by side to carry the current in the armature coils.

The following table will help in determining the horse-power needed to drive Gramme dynamos :—

Nos.	*Watts.*	*C.P.*	*H.P. Required.*
1	120	30	$\frac{1}{4}$ to $\frac{1}{2}$
2	250	65	$\frac{1}{2}$ to $\frac{3}{4}$
3	550	140	1
4	1,650	430	$2\frac{1}{2}$

CHAPTER IV.

THE MANCHESTER DYNAMO.

The Manchester dynamo shown at Fig. 65 (introduced by Messrs. Mather and Platt, of Salford, Manchester) now claims our attention. In point of simplicity in construction and in usefulness it is superior to the Siemens and Gramme machines already described.

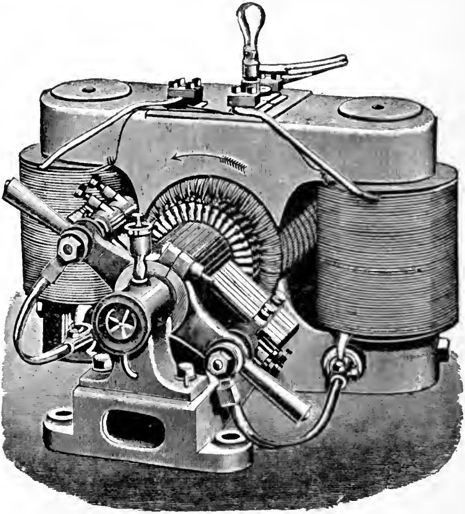


Fig. 65.—Manchester Dynamo complete.

The carcase of a Manchester dynamo may be made up from four castings. These consist of the bed-plate and bottom pole piece in one casting, and the top pole piece and yoke also in one casting, and the two cores. The whole arrangement is shown in section at Fig. 66, where A represents the top pole piece. B the lower pole piece, and C, C, the two cores. From this illustration it will be seen that the two cores form pillars to support the upper pole piece and yoke. The cores should have threaded pins of wrought-iron cast in each end. These pins pass through holes drilled in the top yoke and the bottom bed-plate, and the cores are securely fastened to those parts by nuts fitted to the screwed pins.

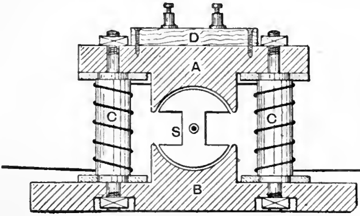


Fig. 66.—Section of Manchester Dynamo, showing winding of Field Magnet Cores.

The cores and pole pieces of all dynamos should be made of the best soft iron, the cores being fitted with flanges. These flange ends, together with a corresponding round area on the yoke and bed-plate, should be turned bright and fitted close together. This is done before the cores are wound with wire, so it will be much easier to wind them thus made up in the form of bobbins; the wire will be protected from injury whilst bolting the parts of the machine together, and the magnetic connection between the cores and pole pieces will be good.

When cores are not thus flanged, it frequently happens that whilst bolting the parts together the iron of the upper pole piece or yoke is forced into electric connection with some of the coils of wire, and this alone is the cause of some failures with this class of machine. The difference in magnetic intensity of the field is often most marked when cores are thus carefully brought into close connection with the pole pieces. As the efficiency of the machine depends largely upon its field magnets, this point should not be neglected.

Figs. 67, 68, and 69 show how the flanges may be put on; Fig. 67 shows the core as in general use; and Fig. 68 the same core with a light fillet cut in a lathe, on each end. This core must fit the hole in a wrought-iron collar or washer when the collar is hot, and when cold the collar will be firmly fixed. Fig. 69 shows the collars shrunk on the core and turned up bright. The field magnet cores may be wound with wire in the same manner as those of the Gramme machine; that is, so as to make the top a north pole and the bottom a south pole, as described in Chapter III., where the method of connecting the ends is also given.


Fig. 67.

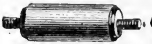


Fig. 68.

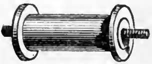


Fig. 69.

Fig. 67.—Magnet Core for Manchester Dynamo.
Fig. 68.—Core with Fillets to receive Flanges.
Fig. 69.—Core Fitted with Iron Flanges.

The ring or the H-girder forms of either solid or laminated armatures may be easily adapted to the Manchester field. In some of these machines Pacinotti cogged armatures are employed; in some others the Gramme ring. For small armatures the H form is convenient, and will be most efficient when built up of laminated plates, as shown at Fig. 10 (p. 16). When armatures of the Gramme or Pacinotti type are used, it will be necessary to build up the commutator as described in the last chapter for a Gramme machine, because we must have a commutator with several sections to receive the ends of the armature coils. But when the H-girder form of armature is chosen, we must also select the two-part commutator used in the Siemens machine, and illustrated at Figs. 33, 34, 35 (pages 29 and 30).

The massive and broad cast-iron bed-plate carries the bearings on each side of the pole pieces, and these are set wide enough apart to admit a long armature spindle. We have therefore room enough for a rocker arrangement and adjustable brush-holders such as those shown at Figs. 60, 61, 62 (pages 55 and 56). The rocker works on a gun-metal sleeve fixed to the inside of one of the brackets. The brushes are best made of copper wire gauze soldered to thin strips of sheet copper. Connections between them and the wires should be made as directed for the Gramme machine.

The instructions for winding the armature and all other necessary particulars in the chapters on the Siemens and Gramme machines apply equally to a machine with field magnets of the Manchester type, and, indeed, to all others.

The following table gives particulars of Manchester dynamos of various sizes.

LIST OF MANCHESTER TYPE DYNAMOS.

Size of Cores. Inches.	*Armature. Inches.*	*Wire on F.M.'s.*		*Wire on Armature.*		*Output obtainable.*			*Revs. per Min.*
Diam. Lgth	Diam. Lgth.	Lbs.	s.w.g.	Lbs.	s.w.g.	Volts.	Amps.	C.P.	
1½ × 4	3½ × 2	6	22	1½	22	40	3	30	2,500
2½ × 6⅛	4⅞ × 2½	10	22	4	20	50	5	65	2,000
3 × 7¼	6 × 6	20	20	4	16	50	10	125	1,500
4 × 10	7 × 7	90	16	12	16	50	30	400	1,200

All the above machines are intended to have laminated cogged ring armatures. That the last is to be wound with two strands of No. 16 wire run side by side, and wound on together. This is found more convenient for winding than a coarser wire, and the effects obtained are equally good. After winding on two strands in this way, the ends should be bared, twisted together, and soldered, before fastening them to the commutator bars. Large machines are furnished with Gramme armatures, often wound with forty or more coils of wire. The small machines have fewer coils on their armatures. Some large machines have also compound wound field magnets—that is, the cores are wound with two sizes of wire, the smaller connected in shunt with the armature, the larger being in series with the armature winding and outer circuit. In the small machines above described, the field magnet coils should be connected in shunt with the armature. In making arrangements for connecting the machine with the outer circuit, it will be advisable to mount a slab of polished mahogany or other hard wood on the top of the dynamo, as shown in section at D, Fig. 66, and screw the terminals into the wooden slab as shown.

CHAPTER V.

THE SIMPLEX DYNAMO.

This chapter will describe the construction of a small dynamo, or motor, made almost entirely of wrought-iron forgings, which can be obtained from any smith or made by the dynamo maker himself.

This machine generates a current of 5 ampères at a pressure of 10 volts; and is about capable of lighting two 8 candle-power lamps when used as a dynamo, and, being shunt-wound, is also suitable for charging storage batteries. When used as a motor, running at about 2,500 revolutions per minute, its power will be about $\frac{1}{15}$ h.-p. The current required will be about 5 ampères at 15 volts.

To drive this machine about $\frac{1}{8}$ horse-power would be required. An engine to develop this horse-power would have the following dimensions:—Cylinder, 2 in. bore, 2 in. stroke; revolutions of fly wheel, 200 per minute; boiler about 18 in. by 9 in.; pressure, 20 lbs. on square inch.

The armature is of the old Gramme ring type, constructed of soft iron wires over-wound with insulated copper wires. About 1½ lb. of No. 20 to 24 s.w.g. iron wire will be required, and also a circular wooden mandrel, or former, of shape and dimensions shown in Fig. 70. This former should be turned from hard wood, with one of the flanges or cheeks removable, so that the iron ring when completed may be slipped off; for the same purpose the former should be covered with a layer of smooth paper, the edges of which may be held in place with sealing-wax. To wind on the iron wire, the former should either be mounted between the centres of a lathe, or a pin should be driven into the centre of each end, and the former mounted between two wooden supports, as shown in Fig. 70. The wire should be wound upon the former in even layers, with a coat of shellac varnish between every two layers, until the outside diameter of the ring is $2\frac{3}{8}$ in.; the thickness of the core will then be about $\frac{3}{8}$ in. The whole surface of the armature should be coated with shellac varnish, and the armature and former placed in a hot oven until the shellac melts and binds the iron wires together. When cool, the removable cheek may be unscrewed, and the armature should then slip off the former easily. The armature should then be insulated by entirely covering it with silk tape, the edges of which must overlap, and the surface then coated with shellac varnish. When dry, the winding of the armature may be proceeded with. It is not essential for the iron wire of the armature coil to be in one continuous hank or coil; the core may be built up of a number of hanks, provided that the length of wire contained in each is considerable, and that each added piece is properly joined to the wire last wound. To join the wires, twist the ends together, coil the joint upon the layers of wire previously wound, and coat with shellac varnish. When this is hard, file the joint down level with a smooth file, again varnish, and proceed with the winding.

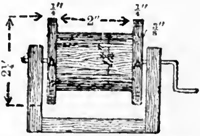


Fig. 70.—Mandrel or Former for making Core of Armature of Simplex Dynamo.

The armature is completely overwound with three layers of No. 20 S.W.G. double cotton-covered copper wire divided into twenty sections or coils, each section having twenty-four turns of wire, the whole weighing about ¾ lb. Before proceeding to wind on the wire, the armature should be firmly fixed to a bench or table by passing a strip of hard wood through the interior and fastening the strip to the bench by screwing in the manner shown in Fig. 71. For the purpose of facilitating the winding and also to keep the armature properly balanced, it is best to divide the armature with a pair of compasses into a number of equal parts, and to treat each part separately. Thus, if the armature is divided into four parts, five sections will be allotted to each part, and the coils can be arranged so as to fill the spaces allotted to them. A sufficient length of wire to reach twenty-four times around the armature, with about one foot over for connections, etc., having been cut off, one end is fastened to the hardwood strip, as shown in Fig. 71, and the wire is then carried over the top of the armature and threaded through the inside, and pulled tight. This is repeated three times; the last inside turn rests upon the two wires previously wound, as represented at A, Fig. 72. The

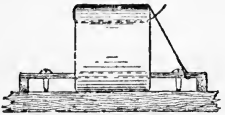


Fig. 71.—Clamp for Armature Core.

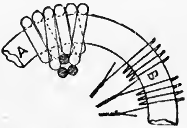


Fig. 72.—Method of winding Ring Armature.

wire is thus wound alternately upon the interior surface of the armature and upon the preceding turns until eight turns have been completed, when the wire is temporarily fastened to the hardwood strip until the next layer is commenced.

The second section is commenced and ended in the same way, and the winding proceeds thus until about five or six sections have been wound upon the armature. The outside wire should be beaten down flat with a small wooden mallet, and the wires on the inside surface should be pressed with a wooden rod for the same purpose. A coat of shellac varnish should then be applied to the wires, and when this becomes hard the second layer is proceeded with in exactly the same way as the first layer, with the exception that the wires on the inner surface of the armature are arranged between those already wound, as represented in Fig. 72, where the white circles show the first layer, and the black circles the second layer. When this second layer is completed, the first layer on the second portion of the armature may be commenced, and when two layers have been wound upon half of the armature, the third layer may be wound on in exactly the same way as the first layer.

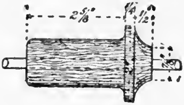


Fig. 73.—Wooden Plug for Armature.

After this third layer is completed, the ends of the sections may be permanently coupled up by cleaning, twisting, and soldering the adjacent ends of the sections together, the finishing end of one section being connected to the commencing end of the next section, as shown at B, Fig. 72. The whole armature should then be coated with shellac varnish. A hardwood plug

(Fig. 73) is next made, through this a spindle of $\frac{1}{4}$ in. steel is driven tight, and the plug is then driven tight into the armature. The armature should now revolve truly upon the spindle, and to prevent the wires from bulging out when the armature is revolving use binding-wires consisting of two bands each of twelve strands of No. 36 s.w.g. copper or brass wire wound upon two $\frac{1}{4}$-in. strips of thin mica or paper and soldered together so as to form solid bands. When these are completed the armature may be connected to the commutator.

The commutator consists of a brass washer, 2 in. in diam. and about $\frac{1}{8}$ in. thick, with twenty countersunk holes drilled at equal distances apart, and fastened against a hardwood disc with twenty brass screws $\frac{5}{8}$ in. long, as shown in Fig. 74. A hole should be drilled through this disc to fit tight on the shaft. After being screwed to the disc the washer is sawn into twenty segments, which, being divided, are insulated from each other though fastened to the hardwood disc. Each of the twenty separate armature sections is composed of twenty-four turns in three layers, each having one commencing end and one finishing end —so there will be a total of forty ends in the whole armature. These are cleaned, and the commencing end of each coil is twisted to the finishing end of the adjacent coil all round the armature. The separate windings will thus form a continuous spiral, and twenty ends will be left. These ends are soldered one to each of the twenty brass screws holding the commutator segments. The ends of the wires are soldered to the ends of the screws, which project through the disc as shown in Fig. 74. The disc should then be driven

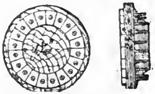


Fig. 74.—Commutator of Simplex Dynamo.

over the spindle and screwed to the centre plug. A layer of string over the screws completes the armature, which is thus represented in Fig. 75.

The field magnet is of wrought iron, of shape and dimensions shown, and consists of the two pole pieces (Fig. 76) and the yoke (Fig. 77). Two coil flanges will also be required. The two pole pieces are fitted so that the armature revolves in the space between with a clearance of about $\frac{1}{16}$ in. They are fixed to the yoke by means of two $\frac{3}{16}$ in. screws or rivets. The coil flanges are of hard wood, zinc, or sheet brass, and are slipped over the magnet core and held in place by the wire. Before fixing the pole pieces, the magnet should be wound with about 3 lbs. of No. 22 S.W.G. single cotton-covered copper wire. The yoke is first covered with a layer of paper, and the wire is then wound upon it in even layers, until the entire space is filled, when a coat of shellac varnish is applied to the wire, and the pole pieces and bed-plate are fixed permanently to the magnet by suitable screws.

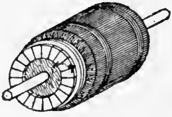


Fig. 75.—Armature of Simplex Dynamo complete.

Cast iron may be used for the field magnet, but as it has a lower permeability than wrought iron the sectional area must be increased. Therefore make the cast-iron field magnet $1\frac{1}{4}$ in. instead of $\frac{5}{8}$ in. in thickness. Wire of the same thickness (22 S.W.G.) may be used as with the wrought-iron core, but more of it will be required.

The bed-plate is also of wrought iron, and is shown in Fig. 79. Through it are drilled three $\frac{3}{16}$ in. countersunk holes for wood screws, four $\frac{3}{16}$ in. tapped holes for holding down the bearings, and three $\frac{3}{16}$ in. clearance holes for fixing the bed-plate to the magnet. The bed-plate is fixed to the yoke by means of two $\frac{3}{16}$ in. screws or rivets, which also fix the lower pole piece, and by a third screw underneath the yoke, as shown in Fig. 77.

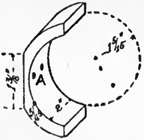


Fig. 76.—Pole Piece of Simplex Dynamo.

The bearings (Fig. 80) are made of brass, and each consists of an upright piece drilled with a $\frac{1}{4}$ in. hole to carry the armature and spindle, and a base-plate soldered to the upright piece and fixed to the bed-plate by two $\frac{3}{16}$ in. screws. One of the bearings is also drilled with a small hole in the upright piece for fixing the brush-holder, as shown in Fig. 80.

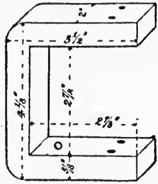


Fig. 77.—Simplex Dynamo Yoke for Magnet.

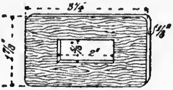


Fig. 78.—Coil Flange.

The brush-holder (Fig. 81) is made of sheet brass, about ⅛ in. thick, drilled with a ¼-in. hole in centre, and two holes at each end to take wood screws, which secure

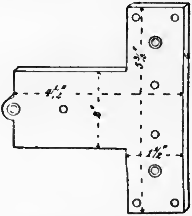
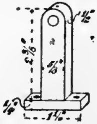


Fig. 79.—Bed-Plate of Simplex Dynamo.

small pieces of ebonite or boxwood. These serve to insulate and carry the brushes, which are made of thin sheet brass or copper at one end drilled with two small holes, for taking round-headed brass screws, one of which fixes the brush to the insulating block while the other



Fig, 80.—Bearings of Armature.

fixes to the brush the flexible connecting wire from the terminal. The screws holding the brushes must not be in metallic contact with the brush-holder itself. A small slot is also made as shown in the brush-holders, so that the brushes may be moved through a small arc until the correct position is found on the commutator. Then the brush-holder is fixed by a small screw, as shown in Fig. 82, which represents the complete machine.

The terminals can be of almost any of the well-known types, as Figs. 14 to 20 (pp. 18 to 20), and may either be fixed upon a hardwood board placed upon the magnets, as shown in Fig. 82, or upon a board carrying the whole machine. In either case the wires from the magnet, coil, and brushes are connected, as shown in Fig. 82.

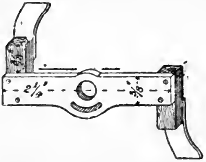


Fig. 81.—Brush-Holder.

The pulley may be of brass, from 1½ in. to 2 in. in diameter, about 1 in. on the face, and fixed to the spindle either by a screw or a key. The belt should be of leather, about 1 in. in width, and not more than ⅛ in. thick. The machine may be finished by giving it a coat of paint and then varnishing.

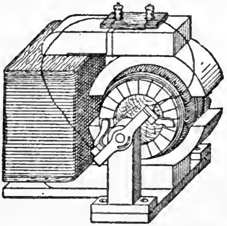


Fig. 82.—Simplex Dynamo complete.

To start the dynamo, run the armature at from 2,500 to 3,000 revolutions per minute, and if the machine is properly constructed it will excite itself after the fields have been initially magnetised by the current from a small battery. If the machine is wanted to run as a motor, about seven or eight chromic acid cells or accumulator cells will be required. It is immaterial which is the north or south pole of the magnet. The commencing end of the field-magnet coil must be connected to one brush, and its finishing end to the other brush.

Below are given dimensions of a shunt-wound dynamo for lighting four 10-candle-power lamps, at a pressure of 15 volts, this being also suitable for charging six accumulator cells if the latter are required. The current will be 10 ampères, and the speed 2,500 revolutions per minute. Armature, 2½ in. wide, 3 in. diameter, core ¾ in. thick, constructed of annealed iron wires, and wound with two layers of No. 16 B.W.G. double cotton-covered copper wire, divided into twenty sections, each in two layers, with eight turns per layer—total turns of wire on armature, 320. Diameter of spindle, ⅜ in.; outside diameter of commutator disc, 3 in.; inside diameter, 1¾ in.; thickness of segments, ⅛ in. Field magnet of rectangular wrought iron 2½ in. wide by 1½ in. thick. Length of field coil, 4½ in.; thickness of pole piece, about ½ in. Flanges of bobbin, about ¼ in. thick. Bobbin wound with about 11 lb. No. 18 S.W.G. single cotton-covered copper wire. With an engine running at 300 revolutions per min., and a flywheel of 18 in. diameter, a pulley about 2¼ in. diameter by 1½ in. wide would be required on the armature spindle to get 2,500 revolutions.

CHAPTER VI.

CALCULATING THE SIZE AND AMOUNT OF WIRE FOR SMALL DYNAMOS.

We commence with the armature, because all other parts are subordinated to it. When a loop of copper wire is placed between the poles of a magnet in such a manner as to vary the lines of magnetism supposed to be passing through it, an electro-motive force is set up in the loop. This principle governs all dynamo-electric machines. The loop of wire, multiplied many times and wound over a core of iron, is named the armature, and the magnet corresponds to the field of the machine.

Amongst other things, the length of wire on the armature determines the voltage ; and in small machines the safe carrying capacity of this wire determines the current obtainable. The size and form of an armature are determined by the desired output of the machine.

The armatures most in use may be classed under one of three types—viz., the shuttle, the ring, and the drum. These three types admit of several variations. In the shuttle type, one coil of wire is wound in the channel between the two cheeks, and the two ends of the coil are attached to two halves of a commutator ring. In the ring type, some six, eight, or more wire coils each of the same length are wound in sections over the ring, the ends of each coil being brought out and soldered to as many bars on the commutator as there are coils on the armature, the finishing end of one coil and the commencing end of the next being soldered to one bar. In the drum type the coils of wire are wound in sections altogether over the armature, not through the ring, as in the ring form, but the coils are connected in the same manner.

The shuttle form of armature is most easily wound and connected, but its use is confined to small machines. This specially applies to solid shuttle armatures, as these soon get so hot as to reduce the output of the machine and endanger the insulation of the wire. When the shuttle is laminated—that is, built up of thin iron plates—this tendency is considerably modified. It is the type of armature usually employed in model dynamos, with fields of the simple horseshoe or Siemens type (*See* Chap. II.).

The ring-type of armature is preferable to the shuttle for larger dynamos, but is very difficult to wind when small, since the space through which to pass the spool carrying the wire becomes more and more contracted with each layer and section of wire wound. It is generally used in dynamos with fields of the Gramme, Manchester, Brush, Kapp, and Simplex types.

The drum type of armature is more easily wound than the ring, since all the wire is wound over the armature outside in sections ; but it is difficult to connect, as the winder is apt to lose sight of the exact order in which the ends of wire are to be connected. If each coil is marked with a different tint or colour of cotton or silk thread, this trouble will be much mitigated.

The voltage obtainable from a shuttle dynamo is roughly determined by the length of insulated copper wire coiled on its armature. The diameter of the wire governs the length that can be got on an armature of a given size. In model dynamos, each yard of active wire on the armature will give about 1 volt (all other conditions being favourable) when moving at a circumferential velocity of 1,250 ft. per minute. This last statement requires some explanation to make it clear. Active wire is that portion of each coil of wire which is employed in cutting through the lines of magnetic force given out by the field-magnets. On a drum armature, all the wire except the parts of the coils over the ends of the drum is active wire. The dead wire on a drum or a shuttle armature should not exceed one-third of the total length employed; but for this efficiency the length of the armature must not be less than three times its diameter. In a ring armature, the relative quantities of dead and active wire will depend upon the thickness of the ring.

The circumferential velocity of the wire coils may be taken to be the same as that of the periphery of the armature on which they are wound. As the circumference of a ring or drum is 3·14 times its diameter, multiply the diameter of the armature in inches by 3·14 to ascertain its circumference in inches. This done, find how many times it will have to turn to cover a foot length, and multiply this number by 1,250 to find how many revolutions the armature must make in a minute to produce one volt from each active yard of wire in its coils. It will thus be seen that the voltage is conditional on the speed of the armature; it is also conditional upon the strength of the magnetic field, which must be at its maximum to get the best result. The following table gives particulars of the weight, resistance, carrying capacity, etc., of copper wire in sizes on the Birmingham Wire Gauge.

PROPERTIES OF B.W.G. COPPER WIRES.

No. B.W.G.	*Diameter. Inches.*	*Approximate Yards to lb.*			*No. of Turns per Inch.*		*Approx. Resist. in Ohms per lb.*	*Length in feet per Ohm.*	*Carrying Capacity in Ampères.*
		Bare	Silk	Cotton	Silk	Cotn.			
8	·165	4·05	4	4	5	5	·00475	2564·1	40
10	·134	6·14	6	5·8	7	6	·0109	1666·6	28
12	·109	9·28	9	8·8	9	8	·0249	1098·9	18
14	·083	16	15·7	15·5	11	10	·0741	666·6	10
16	·065	26	25·5	24	14	13	·1971	400	6
18	·049	47·9	47	45	19	16	·6629	212·7	3
20	·035	85	83	80	25	23	2·095	120·4	2
22	·028	131	129	120	29	27	4·976	77·5	1·5
24	·022	176·4	173	162	34	30	9·009	57·8	1

Carrying capacity in ampères is calculated at about 2,000 ampères per square inch. The safe carrying capacity of the wire is the maximum current it will carry without heating to such an extent as to affect the insulation seriously. In a series shuttle dynamo, the current in the outer circuit passes through armature coils and field-magnet coils; therefore the wire on the latter should be of a diameter about equal to that on the former. The accompanying tables will serve as a guide to selecting suitable wire for the armature and field-magnet coils. The following table deals with wires on the Standard Wire Gauge.

Properties of S.W.G. Copper Wires.

			Weight in lb.		Resistance in Ohms.		No. of Turns per Inch.			Current in Ampères.		
No. S.W.G.	*Diameter. Inches.*	*Sectional Area. Square Inches.*	*Per 1,000 yds.*	*Per mile.*	*Per 1,000 yds.*	*Per mile.*	A	B	C	*At 1,000 ampères per square inch.*	*At 1,500 ampères per square inch.*	*At 2,000 ampères per square inch.*
22	·028	·0006	7	12	40·78	71·8	24	28	26	·6	·9	1·2
20	·036	·0010	12	21	24·11	43·4	20	26	23	1	1·5	2
19	·040	·0012	15	26	19·98	35·2	18	23	20	1·2	1·8	2·4
18	·048	·0018	21	37	13·88	24·4	16	20	17	1·8	2·7	3·6
17	·056	·0024	28	50	10·2	17·9	14	17	15	2·4	3·6	4·8
16	·064	·0032	37	65	7·6	13·6	12·8	15	14	3·2	4·8	6·4
15	·072	·0040	47	83	6·11	10·7	11·5	13	12	4	6	8
14	·080	·0050	57	102	5·	8·8	10·5	11	10	5	7·5	10
13	·092	·0066	76	135	3·78	6·6	9·5	10	9	6·6	9·9	13·2
12	·104	·0085	98	173	2·95	5·2	8·5	9	8	8·5	12·75	17
11	·116	·0105	122	215	2·36	4·2	7·5	7	6	10·5	15·75	21
10	·128	·0128	148	262	1·95	3·4	7	6	6	12·8	19·2	25·6
9	·144	·0162	188	332	1·55	2·7	6	5	5	16·2	24·3	32·4
8	·160	·0201	245	409	1·26	2·2	5·7	4	4	20·1	30·15	40·2

The resistances given above are for 100 per cent. conductivity copper at a temperature of about 65° F.

Under the heading "No. of turns per inch" will be seen three divisions—A, B, and C. Of these B and C refer to wires which, in the small sizes, have special thin coverings of silk and cotton respectively. Under A the insulation is reckoned at the rate of 12 mils $= \frac{3}{250}$ in. of double cotton in sizes below No. 16. Above this size the average covering is about 14 mils, varying from 10 to 20 mils, however.

The output of a dynamo — that is, its electrical power—is generally calculated in watts. This is obtained by multiplying the total voltage by the ampères. But as this method of stating a dynamo's output admits of uncertain interpretation, it is best to specify the volts and ampères separately.

In a series machine the field magnet coils are connected in series with the outer circuit. The magnetism in the fields, therefore, varies inversely as the resistance of the circuit, being less when the resistance is high than when it is low. In a shunt-wound machine the field magnet coils are connected in a shunt with the outer circuit. There are, therefore, two paths open to the armature current: one through the field magnet coils, and the other through the outer circuit. The resistance in the outer circuit being lower than that of the field magnet coils, more current goes by way of the outer circuit than goes round the coils, but when the resistance of the outer circuit is increased, more current goes by way of the coils, and this raises the magnetic intensity of the fields. The effect of this is to raise the voltage of the current, and enable it to overcome the extra resistance. In a compound-wound machine the field magnet coils are partly of thick wire connected in series with the armature and outer circuit, while a small wire of high resistance is connected in shunt. This form of machine may be made to give almost a constant potential difference at the terminals.

Each style of winding has its own peculiar advantages, adapting it to the kind of work to be done by the machine. A shunt-wound dynamo becomes self-regulating to a certain extent; for as the lamps are switched off the resistance in the outer or lamp circuit becomes greater, and more current is shunted through the field coils, thereby generating a higher voltage to overcome the increased resistance, while a compound-wound dynamo is self-regulating to a still greater extent.

A rough rule for shunt-wound machines with about 90 per cent. efficiency is as follows :—Let the resistance of the armature be represented by 1, that of the outer circuit by 20, then that of the field magnet circuit should be 400—that is to say, the outer circuit should have a resistance twenty times that of the armature, and the field magnet circuit should have a resistance four hundred times that of the armature. In a series machine, the field magnet coils should have a resistance about two-thirds that of the armature coil. In a compound machine, the resistance of the series coils should be the same as that of the armature. In small machines these proportions have to be considerably modified. In a 300-watt machine—to give 6 ampères at 50 volts—the field magnet resistance may be reduced to 200 instead of 400, and this proportionate resistance rapidly diminishes with each small reduction in the size of the machine, until the smallest workable dynamo will only admit of the resistance of the field magnet coils being some twelve or fifteen times that of the armature coil. It is almost impossible to determine exactly the output of such small machines; for apart from the variations from theoretical rules, others are likely to crop up through differences in the qualities of iron employed, hardness of wire, irregular or loose winding, insulation, connections, size, form and make of commutator, and quality, position, and pressure of brushes, etc.

Properly designed castings for the carcase of the dynamo usually have ample space allowed for winding sufficient wire to suit the electrical output of the machine. If the carcase of the machine has to be forged or cast, and the rings or punchings for the armature made to order, proper space must be allowed for the wire. By referring to the tables given on pages 78 and 79, the space likely to be occupied by the wire will be found under the heading "No. of turns per inch"—that is, so many turns of wire of a given gauge will lie side by side in 1 in. of space. The channel in a shuttle armature must be large enough to take the required wire without bulging beyond the cheeks. The space between the outer edge of the ring or drum armature and the sides of the tunnel in which it is to work should be sufficient to leave $\frac{1}{16}$ in. between the wire and the sides after three layers of the wire have been wound on. One layer is theoretically the best, but three layers are admissible.

The length of the field magnet cores may be about three or three and a half times their diameter, and provision should be made to admit of enough wire to increase the diameter of the core from two and a half to three times. The space to be occupied by the wire may be ascertained by estimating its length and weight or length per pound, noting how many turns to the inch it will run. Estimate the probable diameter of the wound core, and find the mean between this and the bare core, then multiply this by the factor 3·14, and so ascertain the number of turns and the space likely to be occupied by the wire. Heavy yokes and pole pieces are always admissible, because dynamos work best when the iron in them is in excess of that needed to maintain magnetic saturation. It is also advisable to have a larger carcase than will be actually needed to furnish the required output, since machines may always be safely worked to light fewer lamps than they were designed for; but it is not safe to work them at a higher speed to procure a larger output.

Before the plan for winding the armature can be drawn up, the resistance of the outer circuit—namely, the work to be done by the machine—must first be ascertained. If this resistance is too low, a shunt machine will fail to supply the required current, and a series machine will burn its coils. If too high, no current will be obtained from a series machine, and that from a shunt machine will be diminished. In large machines, carefully wound, an efficiency of 1 volt per foot of effective wire on the armature moving at a circumferential velocity of 1,250 feet per minute has been attained, but, as has been stated, 1 volt per yard is what may be expected from small machines. Although the voltage of a machine may be increased by increasing the speed of its armature, it is not always safe to do so, because an increased voltage will send more current round the field magnet coils, and this may dangerously heat them. In a series machine, all the current passing through the outer circuit also traverses the field magnet coils. In a compound machine, the bulk of all its current passes through the series coils and only a fraction of it through the shunt coils. In a shunt machine, only a fraction of the current passes through the field magnet coils. Consequently, the fields of the series machine are not magnetised when the outer circuit is open, and the fields of the shunt machine are then most highly magnetised. When a machine is run at a higher speed, the brushes should be given a more forward lead, to compensate for increased distortion of the field.

The wires for dynamos may be protected by using indiarubber or gutta-percha dissolved either in benzole or in naphtha. This solution will make an elastic insulating varnish, but it is liable to injury from oil, which renders the varnish soft and sticky. Shellac varnish is one of the best for the purpose. This is made by digesting shellac in methylated spirit, kept in a stoppered glass jar in a warm place for twelve hours. Green or red sealing-wax digested in warm methylated spirit is also used as an insulating varnish.

Few persons can get the calculated amount of wire on an armature, although a full allowance has been made for slack winding. To take an armature in one hand and let the wire run through the fingers of the other, drawing it more or less tight, winding as one would wind up a ball of string, sometimes working evenly, sometimes not, will not do. To wind an armature properly, especially if of either the drum or ring type, is work for two people. Even a shuttle armature should not be attempted by one person unless he is an experienced winder; and even then he will wish he had three hands.

After the wire has been properly paraffin-waxed and drained, it should be wound on as tight as possible, without, of course, breaking it. Any wire that is not perfectly straight, or is in the least respect faulty should be driven well into place by means of a small wooden hammer or by a small wooden stick, neatly squared and smoothed at the end, and used as a punch. Every wire should be made to go as near to its neighbour as possible. It will be seen that winding an armature properly is no light work.

Cheap wire is very bad, for two reasons—one is that the wire itself has a comparatively low percentage of copper, and wire should not be used that has less than 97 per cent., as it gives the armature a needlessly high resistance. The other is that cheap wire has bad, thick cotton for its covering, and consequently occupies space wastefully. Another source of trouble is thick, clumsy taping. There should be just enough to ensure perfect insulation, and no more. Bad taping takes up a lot of room, and space is precious to a winder of armatures. Remember this, and do not be afraid of using the wooden hammer.

In treating the subject of calculating the length of wire for armatures, two types only will be taken—viz., the Siemens H-girder, or shuttle armature (Figs. 83 and 84) and the cog-ring armature (Figs. 85 and 86), as undoubtedly they are the best types of armatures for small-sized dynamos; the former for the very small sizes, and the latter for somewhat larger ones. They are also the easiest kinds to wind and correct, and are therefore very suitable for amateur workers.

As an illustration, it would be best to take a sample armature, fix upon a certain gauge of wire, and follow up the working to get at the weight and length of wire required; by this means the reader will have an example at hand to work from in cases of armatures of other sizes.

The first example will be a laminated shuttle armature, 2½ in. long, 1½ in. in diameter (Figs. 83 and 84),

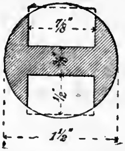


Fig. 83.—Section of Shuttle Armature.

having the web flush with the ends. An armature of this size would probably have wire spaces ⅞ in. wide, and by

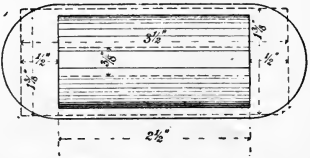


Fig. 84.—Side View of Shuttle Armature.

making the segment of the circular area form a rectangle of equal area, as shown by the dotted lines in Fig. 83, the wire space would be ½ in. deep, leaving ⅜ in. for the thickness of the web. In calculating shuttle armatures the shaft need not be taken into consideration, as it does not affect the amount of wire that will go into the channels, though it makes the winding at the ends irregular, which cannot be helped; the slight extra length required through this irregularity can in practice be neglected.

The next operation will be to make a sketch of the side of the armature, as in Fig. 84, where the full line will represent the last coils of wire; then by setting ½ in. off at each end, the longest coil is obtained as a rectangle. (*See* the dotted lines in Fig. 84.) The next thing to find is the mean length of all the turns. This will be the shortest turn, added to the longest turn, divided by 2. The shortest length is one of the turns in the first layer, and will be, of course, rather more than (2 × 2½) + (2 × ⅜) = 5¾; the longest length will be the length of the sides of the rectangle in dotted lines (Fig. 84), which was shown to represent the longest coil; then the longest turn will be (2 × 3½) + (2 × 1⅜) = 9¾; so the mean length of all the coils will be 5¾ + 9¾ ÷ 2 = 7¾ in.

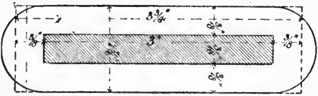


Fig. 85.—Section of Cog-ring Armature.

For this example, No. 20 s.w.g. cotton-covered wire will be taken to wind the armature. Upon looking in the tables (p. 78), it will be found that this wire can be coiled twenty-three coils to the linear inch. Should there be no tables at hand, take a spare piece of wire of the gauge to be used, and coil it round neatly on anything smooth, and count how many coils go to an inch. As the wire space is ⅞ in. wide, and ½ in. deep, it can be assumed that twenty coils, eleven layers deep, can be got into the space; this will make 220 coils in all. Now it has been found that the average, or mean coil of all the coils is 7¾ in. long; therefore the total length of wire will be 220 × 7¾ = 1,705 in., or 47 yds., 1 ft., 1 in.—say 47 yds. No. 20 s.w.g. cotton-covered wire goes 80 yds. to the pound, so the amount of wire for this armature would be 7 yds. over ½ lb., or say ½ lb. Of course, it will be observed that should the armature be solid, with the web set back from the ends, much less wire can be got on, also the winding would be neater and more compact if the shaft did not run through the web.

For the other example a laminated cog-ring armature will be taken, 5 in. in diameter, 3 in. deep, having twelve cogs; wire spaces ⅝ in. wide and ⅜ in. deep, with the core of the armature ⅜ in. thick at the wire spaces and ¾ in. thick at the cogs. (*See* Figs. 85 and 86.) This armature it is proposed to wind with No. 12 s.w.g. cotton-covered wire. The mode of operation is very similar to the example above, one whole coil being calculated first. A section of the armature core through a wire space must be drawn as in Fig. 85; then setting off the ⅜ in., the depth of the wire space all round, the longest mean coil is found as a rectangle, as shown by dotted lines.

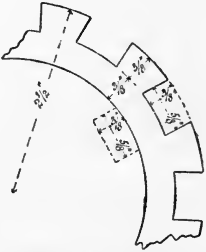


Fig. 86.—Side View of Cog-ring Armature.

Proceeding as before, the mean length of all the coils is found; thus the shortest (2 × 3) + (2 × ⅜) = 6 ¾ in.; and the longest (2 × 3¾) + (2 × 1⅛) = 9¾; then the mean coil will be 8¼ in. long. The wire tables (p. 78) show that eight coils of No. 12 S.W.G. cotton-covered wire go to the linear inch; so in the space ⅝ in. × ⅜ in. there will be room for five coils, three layers deep, which will make fifteen coils in all. As the mean coil is 8¼ in. long, the total length will be 15 × 8¼ = 123¾ in.; but as there are twelve separate coils on the armature the total length of wire for the whole armature will be 123¾ × 12 = say 41 yds. No. 12 S.W.G. cotton-covered wire runs 8·8 yds. to the pound; so between 4½ lb. and 4¾ lb. will be enough.

A simple way to determine the mean length of the coil is to add together any two adjacent sides of the rectangles forming the longest and shortest coils. Taking the first example (p. 85), shortest coil = (2 × 2½ in.) + (2 × ⅜ in.); longest coil = (2 × 3½ in.) + (2 × 1⅜ in.); mean coil = half the sum of these. Now, the shortest coil may be written: 2 (2½ in. + ⅜ in.). Similarly, the longest coil = 2 (3½ in. + 1⅜ in.): and combining the two, and talking half the sum for the mean coil, we get

$$\frac{\cancel{2}\{(2\tfrac{1}{2}\text{ in.} + \tfrac{3}{8}\text{ in.}) + (3\tfrac{1}{2}\text{ in.} + 1\tfrac{3}{8}\text{ in.})\}}{\cancel{2}}$$

which is equal to mean coil; and by cancelling the multiplier and divisor of fraction, we have left, 2½ in. + ⅜ in. + 3½ in. + 1⅜ in. = mean = 6 in + 1¾ in = 7¾ in.; and in the second example, 3 in. + ⅜ in. + 3¾ in. + 1⅛ in. = mean = 6¾ in. + 1½ in. = 8¼ in.

CHAPTER VII.

AILMENTS OF SMALL DYNAMO-ELECTRIC MACHINES, THEIR CAUSES AND CURES.

To localise the faults common to dynamos, we shall require a battery of three or four cells of a strong and constant type, a galvanometer or current detector, such as those used by electric-bell fitters, and a magnetised needle or a pocket compass. To repair the faults we shall need a soldering-iron, some soft solder, and some resin to solder faulty joints; a pair of stout pliers, a screwdriver, small spanners to fit the nuts on the machine, and some soft cotton or tape, or both, well soaked in melted paraffin wax.

The best battery for the purpose is the single fluid bichromate battery—that is, a battery composed of jars or wide-mouthed bottles of glass or stoneware, each holding a pint. Each jar contains a plate of amalgamated zinc between two plates of carbon, and is charged with a liquid composed of 3 ozs. bichromate of potash dissolved in a pint of water, and 3 ozs. of sulphuric acid. This liquid must be allowed to cool before the zinc plate is placed in it.

The zinc plate in one cell must be connected to the carbon plate in the next cell by a stout copper wire, say No. 16 S.W.G., and all the cells must be thus connected so as to leave one zinc plate free at one end of the row, and one carbon plate free at the other end of the row. About 2 ft. of No. 18 or No. 20 S.W.G. wire, attached to these end plates by suitable binding-screws, will serve to connect the battery with the galvanometer and the machine. A steel darning-needle, magnetised by rubbing it on a permanent magnet, and suspended by a piece of cotton to hang horizontally, will serve as a substitute for a pocket compass. With this apparatus the following faults may be localised.

If the cores of the magnets are not magnetised, no current will be generated in the armature coil. If one of the field magnet coils of an overtype or undertype machine is wound in the wrong direction, both pole pieces may have a like magnetism, and the same negative result will be obtained. One pole piece must have an opposite polarity to the other. The compass needle being held near the pole pieces of an ordinary two-pole machine, one of them should attract the north pole of the needle, and the other repel it. The machine should be tested in this way whilst the armature is at rest, and also when it is running. If the coils are wrongly connected, there may be a similar result. If the compass needle does not indicate any magnetism, or only a feeble magnetism, it may be assumed that the pole pieces are not magnetised.

The whole of the armature current in a series machine, and a portion of it in a shunt machine, will be employed in maintaining the magnetism of the field; we must be careful so to convey it through the field-magnet coils as to retain the polarity of the cores induced initially by the battery current.

A series-wound dynamo employed in depositing metals from their solutions, or in charging accumulators, is liable to have its poles reversed by a back current from the plating-vat or the accumulator cells. For this reason series dynamos are not suitable for such work. The polarity of the core is also reversed when current is sent through its coils from a battery, or another dynamo, to run the machine as an electric motor. Compound-wound machines are also liable to a reversal of their magnetism from a similar cause, owing to a high reverse current passing through the series coils. A shunt-wound machine can only be reversed by such means when its field-magnet coils are wrongly connected to a battery; therefore, a shunt-wound machine should always be used for charging accumulators and for electro-depositing work. This altered polarity of the field-magnets may be detected by the compass needle being held to them, and the original magnetism can be restored by the means adopted at first for magnetising the cores.

Magnetism neutralised, which may also be named short-circuiting the magnetic poles, occurs when the poles are bridged by a mass of iron, as when an undertype field is bolted direct to an iron bed-plate, or an overtype field is bridged by an iron plate secured to the pole pieces. When an air space is left between the polar extremities of a horseshoe magnet, the magnetic lines of force may be supposed to stretch across from one pole piece to the other, and are then in a position to pass through the armature coils. But when a piece of iron bridges these polar extremities, the greater number of the magnetic lines pass by way of this bridge, and so are diverted through the armature from their useful path, and, as there are, therefore, few or no lines of force passing through the armature, there will be a very faint current from the machine, or none at all.

The field-magnets have been short-circuited by placing a guard of thick iron over the armature gap The guard over the armature space of an overtype dynamo should be of zinc or gun-metal; and if it is necessary to have a metal bed-plate for an undertype dynamo, brackets of gun-metal or of zinc should be interposed between the magnet poles and the iron of the bed-plate.

If the machine does not give a current or the desired effect, though the magnetic properties of the field have been tested as directed and found perfect, leakage or short-circuiting of the coils may be suspected. To detect this we must employ a battery and galvanometer, as before explained. Leakage most frequently takes place between the wire of the coils and the iron of the field magnets or the armature. Perhaps the rough corners on the castings have not been made smooth. Perhaps the iron has not been coated with a sufficiently thick layer of varnish, paraffined tape, or calico; or the wire has been pulled tight over these rough or unprotected parts, and the insulation has been cut through, thus bringing bare copper into contact with bare iron. As a consequence, the current takes a short cut by way of the iron instead of going through all the coil of wire, and the result is seen in a diminished output from the machine.

The following is a rough-and-ready means frequently adopted for discovering this fault. Disconnect the ends of the field magnet coils from their terminals, and connect one end of the coils to one terminal of the battery. Then take a long exploring wire and connect to the opposite terminal of the battery, and with the free end of this scrape the iron-work and metal-work of the machine at several points. If any bare part of the wire coil is touching the bare iron of the machine, a bright spark will be seen to flash from the part of the machine touched with the exploring wire. By disconnecting the two coils from each other and testing each separately, the faulty one may be discovered. The armature coils may be tested in a similar manner—in fact, they must be tested for leakage as well as those of the fields. It is advisable, however, in both cases to place the galvanometer in circuit by connecting the battery to it, and then to connect the exploring wire to the galvanometer. If the needle moves, it shows that there is a leakage, however small or large this may be, but the rough test will only reveal a bad leakage.

Leakage of another form may occur between adjacent turns or layers of wire in the same coil, and is due to the stripping off of the insulation, from some such cause as hammering the coils to get them in their proper places, or from pulling them too tight. If a machine is overdriven, or if a series machine is short-circuited, the insulating covering may get burnt off, and thus the coils become short-circuited.

This fault can only be discovered by means of the galvanometer in circuit with the battery. Each coil must be placed in circuit separately, the deflections of the galvanometer needle noted, and these compared. Equal lengths of wire should have equal resistances, and this should be indicated by equal deflections of the galvanometer needle. If the needle swings over much farther when one coil is in circuit than when a similar coil of the same length is tested, we may expect that coil to be short-circuited somewhere, because it offers a less resistance than the perfect coil. Each coil of the armature should be unsoldered from the commutator bars and tested separately in comparison with the others. All faulty coils must be unwound and the fault repaired by winding paraffined cotton or tape over the bare spot.

Leakage sometimes occurs between the commutator bars and the spindle, or between the sections of the commutator itself, or between the brush-holders and other parts of the machine. Any of these leakages may be detected by the galvanometer and one or more cells of the battery. The commutator bars may be accidentally placed in contact with the spindle by using long screws. To detect this fault, attach one battery wire to the spindle and the other to the galvanometer, then touch each bar with the free wire from the galvanometer and watch the indications of the needle. If the needle moves when a bar is touched, that bar is in contact with the spindle. Any faulty screw must be withdrawn, and a shorter one used. If the bars are accidentally connected by metal dust, or by expansion of the sections whilst heated, this fault may be detected by placing one wire from the battery on one bar and the wire from the galvanometer on the next bar. The coils must be disconnected from the bars whilst this is being done. Sometimes the brush-holders are not insulated from the machine. This fault may be detected by testing each separately with the body of the machine in circuit, and then testing the two together. If all is right, no current should pass between them and the machine or between the two holders when the brushes are off, and they are disconnected from the outer circuit. Perfect insulation at these points is of the greatest importance.

A machine tested at all points indicated above and found all right, or the detected faults put right, and yet that will not give satisfaction, may have a fault in the brushes. All brushes, in any type of machine, should be held in suitable brush-holders fixed to an insulated rocker, or in insulated sleeves attached to such a rocker. Fixed brushes on standards, or on blocks attached to the machine, give much trouble, since they can only be adjusted by the exercise of much time and patience, and even then cannot be trusted to remain right for any length of time. The most inexpensive and efficient material for brushes in small dynamos is copper gauze, cut into strips of suitable width and length, and formed into pads by soldering the strips together at the ends to go in the brush-holders. As these pads have very little elasticity in them, it is advisable to back them with a strip of spring steel, German silver, or brass, so as to ensure enough pressure to keep them in good contact with the commutator. Machines frequently fail because of having hard brass brushes, which press unevenly on the commutator, or get thrown out of contact when the machine is driven at a high speed. Pads of copper gauze bear and wear more evenly than springs of hard brass.

When these pads are fixed to a rocker, they may be easily adjusted to any position. The theoretically right position for the brushes is for their ends to bear on the commutator bars opposite the centre of the open spaces between the field magnets. The position practically right is always in advance of this, because the armature current distorts the lines of force in the magnetic field. This forward position or lead of the brushes must be found by experiment, because it varies with the type and speed of every machine. As a rule, the highest speed demands the most forward lead. If the machine is connected to the thick coil of a suitable ammeter when driven at the required speed, and the brushes are moved until the best effects are noted by the deflection of the needle, this will be the best position for the brushes.

Sparking at the Brushes.—The machine may run all right, and give a fairly good current for a short time, but there may be much sparking at the brushes, burning them away and burning pits in the commutator. This shows defective construction or bad adjustment of the brushes. The likely faults in construction are: Coils of a varying length and resistance on the armature, insufficient resistance in the field magnet coils, or leakage between the armature coils and the carcase of the machine. This last defect may be found by examining the armature coils. Perhaps these touch the iron occasionally, and rub off the insulating coating. This may be due to too much end-shake of the armature spindle, to a worn bearing, or to a loose bearing allowing the armature to wobble.

A small washer on the spindle will correct too much end-play, tightening the nuts will remedy a loose bearing, but a worn bearing must be bushed with brass to cure side-shake. If leakage occurs, the worn spot should be coated with varnish worked in well between the folds of the wire. Sparking may indicate that too much work is being thrown on the machine. Sparking due to bad adjustment of the brushes can be cured by altering their lead, as described in the previous section (p. 94).

Broken Armature Wire.—Such a wire can be mended as follows:—If it is *outside* the winding, bare and clean the two ends, twist and solder them together, then paint the joint over with either Brunswick black or red sealing-wax varnish. If it is *in* the winding, bare and bevel the two ends, tin the bevels, and sweat the joint together; then work up to as near the size of the wire itself as possible, relap the joint with silk, and dip it in melted paraffin wax, or paint it over with Brunswick black.

Running Hot.—Some of the best designed and constructed machines will get too warm after a day's run on heavy work. The passage of an electric current through the wire coils will always warm them more or less, and much of this rise of temperature is unavoidable. When the temperature rises considerably, as when the field magnet coils feel quite hot if touched by the hand, there is always a serious loss in heating the wires, because hot wires offer more resistance to the current than cool wires. The main cause of this excessive heating is an employment of wires too small to carry the current properly; or, in other words, the machine is required to do more work than it is properly capable of. The remedy here is clear enough. But sometimes the heating of a machine is due to defective construction, or it may be due to leakage. Solid iron armatures, and laminated armatures which are not insulated, may get unbearably hot in a short time, because of cross or eddy currents circulating in the mass of iron from end to end of the armature.

When the laminations are separated from each other by an insulating substance (even a thin coat of varnish is sufficient), these currents are broken up, and cannot travel from end to end. Machines with solid iron armatures, or with badly-insulated laminations, will get hot enough to melt the soft solder connections at the commutator and distort the commutator sections. In series and compound machines leakage across the brushes will also heat the coils injuriously. Short-circuiting a series machine may seriously damage it, by charring the insulating covering of the wires.

These are the most common ailments of small dynamos. Others there are, but it will often be found that these are due only to faulty workmanship or to wear and tear.

It may be useful here to say a few words as to the possibility of receiving shocks from dynamos. There cannot be any serious shock to a person handling a dynamo giving a current of low voltage. Neither can a person receive a shock merely by touching the machine with one hand, provided the machine as a whole is insulated from the ground, because the body does not then form a link in a closed electrical circuit. It is unsafe to meddle with large dynamos, or with any part of an electric light circuit in a large installation, even to touching it with one hand only, unless you are thoroughly acquainted with it, because of the uncertainty of knowing when the mere act of touching may complete a circuit.

The general attention which a dynamo requires is similar to that needed by all high-speed machines. Keep all bearings and wearing parts clean and properly oiled. See that the driving-belt is wide enough to take a good grip on the pulley, and thus maintain a good speed without undue tightness. It must also be remembered that, in addition to the bearings, the commutator and brushes are the wearing parts of the machine. The brushes must be adjusted to the proper angle, as before explained. Sparking wears away brushes and commutator very fast, and thus will demand frequent adjustment of the brushes to keep them bearing on the best part of the commutator. When the brushes have cut grooves in the commutator it is necessary to re-true the furrowed part, and sometimes to put in a new segment.

CHAPTER VIII.

SMALL ELECTRIC MOTORS WITHOUT CASTINGS.

The little model shown at Fig. 87, if made according to the following instructions, requires no castings and no lathe for its successful construction. It is also within the reach of the younger readers of this book who have an idea of using a few tools, and will exercise a little ingenuity and patience. The motor, when complete and judiciously painted with such simple colours as red sealing-wax varnish and Brunswick black, looks very presentable, to say nothing of its use in illustrating the laws of electro-magnetism.

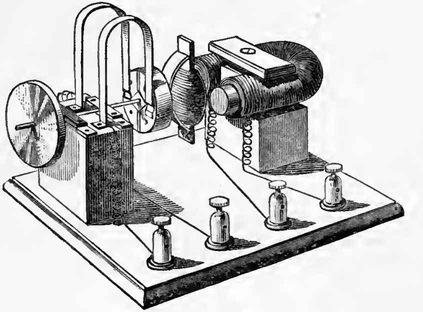


Fig. 87.—Simple Electric Motor complete.

For the field magnet get a piece of ⅜ in. round wrought iron 4½ in. long, as soft as possible, and bend it into the form of a horse-shoe, with the ends ⅞ in. apart on the inside; go over it with a file to take the roughness off, and then file up the two ends true and square one with the other. Cut a long strip of paper —¼-in.-wide newspaper will do—and paste it well, and wind it round the horse-shoe until there are about three thicknesses on all over, except within ⅛ in. from the ends; paste the outside of the paper all over, and go over it with the fingers to get it even; when this is dry give it a coat of Brunswick black.

This magnet does not require any bobbins, so we can go straight on winding it with some No. 28 S.W.G. silk-covered copper wire. Begin just short of the edge of the paper cover, with a half hitch, leaving the end about 6 in. long; wind the wire on close and even until reaching the other end, just within the edge of the paper; then, still winding the same way, go back over the first coils, but be careful that the wire does not slip, and that the second row does not sink between the first.

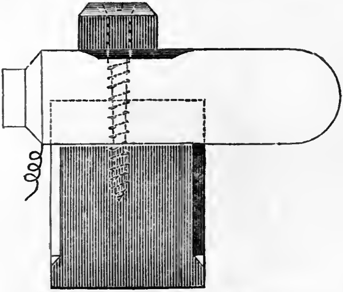


Fig. 88.—Side Elevation of Field Magnet and Block.

After going back about ¼ in. or so, fix the end by giving two or three turns on the opposite leg of the magnet or by any other way that may be convenient, and give the whole magnet another coat of

Brunswick black; let this get dry (it does not take long), and go ahead again, always applying a fresh coat of varnish when an end is reached. By taking care in turning, and repeating the coats of Brunswick black, all danger of slipping will be avoided.

The wire coils will not lie close together on the outside of the bent part of the iron core. Keep them close

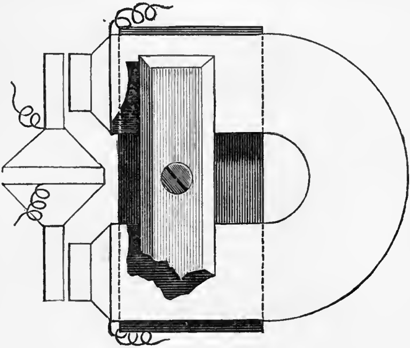


Fig. 89.—Plan of Field Magnet and Block.

on the inside, however, and make them radiate nicely for the sake of appearance; winding round the bent part in this way will not interfere with the working.

When the winding has been continued till the coils laid measure about ⅝ in. in diameter all over, finish off at the opposite end from which you began by tying a piece of thread close up to the finish, leaving another 6-in. length of wire. Wind the thread in different directions, and fasten it off with a knot. See that the ends of the iron core are flat and bright. (*See* Figs. 88, 89, and 90.)

For the armature take a small piece of soft wrought iron, 1⅝ in. long, ⅛ in. thick, or a little thicker, and ⅜ in. wide; file it smooth all over, and take off all sharp edges. Get a short strip of paper, ⅝ in. wide, and paste it round the exact middle of the iron until there are three or four thicknesses on. Give the paper a coat of Brunswick black, and let it dry.

Now begin to wind the armature, using No. 36 S.W.G silk-covered copper wire. Take great care in winding the armature, turning backwards and forwards as with the field magnet, giving each layer a coat of Brunswick black, and wind on as much wire as the armature will accommodate. The more neatly the work is done the more wire will be got on, and the better will be the results; finish off in the middle, and leave tags at each end about 2 in. long. See that the coils are not more than ⅞ in. across in front, or the magnet will rub them. Fig. 91 (p. 102) will show what is meant. While winding the armature, it may be tried in different positions against the magnet, to see that the coils are quite clear of other parts, for if they do not touch while the armature is against the magnet, it may be assumed that they will be all right afterwards.

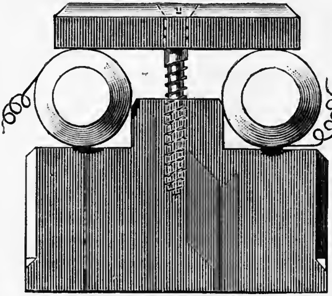


Fig. 90.—Front Elevation of Field Magnet and Block.

The brushes are simply two thin copper strips, 3 in. long and $\frac{3}{16}$ in. wide, bent to the required shape, with a piece of silk-covered copper wire about 6 in. long soldered to each, and each having a small hole drilled at one end to take a small wood screw, as shown in Fig. 92.

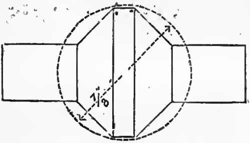


Fig. 91.—Armature, showing $\frac{1}{8}$-in. Limit.

The commutator should be in two parts, arranged so that the brushes work on one face, and not on the rim. This plan has been adopted as the motor is designed to be made without using a lathe, and to true up a round surface is next to impossible without a lathe.

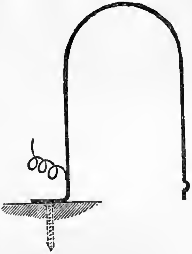


Fig. 92.—Shape of Brush.

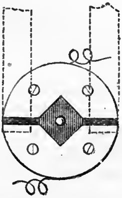


Fig. 93.—Face of Commutator.

For the body of the commutator take a cylindrical piece of hard wood not less than $\frac{3}{4}$ in. diameter, and cut off ⅜ in. of it quite square. A piece of an old round ruler does very well indeed; true up both flat faces, and carefully drill a hole through the exact centre large enough to fit tightly on a thick knitting-needle, 2½ in. of which will make a very good steel shaft.

From sheet copper cut a disc of the same size as the wooden body, and fasten it on the wood with four small wood screws, and counter-sink them as shown in Fig. 93. Cut the copper right through the centre with a file, and saw down through the wood for about ⅛ in; the thickness of a small saw-cut will be quite wide enough for the slits.

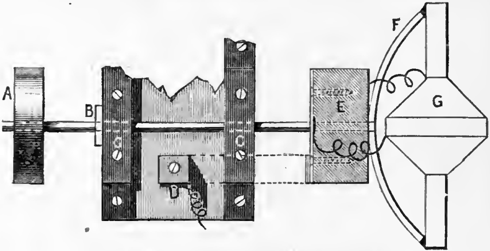


Fig. 94.—Armature Shaft complete.

Having gone so far, take off the two pieces of copper, mark them so that they can be put on again in the same positions, and cut a notch in the middle of each as in Fig. 93, to prevent any chance of contact with the shaft; screw them on again, and glue into each side of the slot two little pieces of boxwood or bone, so that they stand just above the copper. Then file up the whole face, bone strips, and screw-heads to a true and even smooth face, square with the shaft-hole.

Make the yoke for the armature from sheet brass about $\frac{1}{16}$ in. thick. Cut a piece about 1⅝ in. long and ¾ in. wide, and bend it as shown to the right in Fig. 94, so that it will touch the ends of the armature and enclose the coils. It may perhaps be necessary to cut it a little longer than 1⅝ in.; all depends on how much wire has been wound on the armature.

In the centre of this yoke drill a hole to fit the bit of knitting-needle which forms the shaft; then carefully adjust the yoke on the armature so that the hole for the shaft comes *exactly* in the centre of the armature and coils; fasten both together with twine to prevent any chance of shifting, and solder the two ends of the yoke to the two ends of the armature.

Now place the steel shaft through the hole in the yoke, see that it is perfectly perpendicular to the face of the armature, and solder it in, taking care not to drop any hot solder upon the armature coils. As there will not be much chance of truing up afterwards, try to get everything square when fixing in the shaft.

Fig. 95.—End View of Brass Bearing for Armature Shaft.

The shaft bearings are four pieces of brass cut from the same piece as the yoke, or from sheet brass a little thicker; two measure about 1¼ in. by $\frac{3}{16}$ in., and two about ¾ in. by $\frac{3}{16}$ in. They are each drilled, as shown in Figs. 94 and 95, to take four small wood screws and the shaft. The best way to drill the shaft-hole, shown in the centre of Fig. 95, is to fix both pairs of brasses to any spare piece of wood side by side, just in the position they will occupy on the frame, only close together, and carefully drill right through both at once, square and true. Before taking them off mark them all, to ensure getting them back in their places when they are to be fixed.

The stand and blocks can be made of any kind of hard wood preferred. Their form does not matter much, so long as the one at the top of the field magnet is made as shown in Figs. 88, 89, and 90.

The block for the bearings and shaft can be a simple cube; only both blocks must be of such a height as to bring the centre line of the shaft on a level with the centre line of the field magnet ends. The blocks can be glued on the stand after their positions have been determined, or fastened by screws through the bottom of the stand, or they may be fixed in both ways. Four little binding-screws will be wanted for the stand, as in Fig. 87 (p. 98), which is a sketch of the model in its simplest form complete, but not drawn to scale.

When fixing, the commutator, with its copper face outwards, can be slipped on the shaft right up to the yoke, the slits being parallel with the length of the armature. A little strong glue dropped on each side, between the yoke and the wooden back of the commutator, will hold them together quite tight enough, especially if the shaft-hole is not large.

Now bring out the ends of the coil, one to each side of the yoke; cut them just long enough to reach the edge of the copper face of the commutator, but not to press against the yoke; bare the ends, and solder one to each segment of the rim, taking care that no solder runs on up the copper face.

Cut a small disc of stout lead A, solder this on the end of the shaft in such a place that it balances the armature, commutator, etc., and put it on true to prevent any wobbling. This little disc has two uses: it makes the model run easier by means of its balancing power, and it helps the armature over the two dead points.

The magnet may now be screwed tight on its seat, silk ribbon having been previously wound round the coils to prevent the wood cutting them. The brass bearings can then be put on the other block in their proper places, the one farthest from the magnets being flush with the side of the block, so that a little brass washer can work against it. This washer must be soldered on the shaft as shown at B in Fig. 94, where A is a lead disc, C C the bearings, D the brush, E the commutator, F the yoke, and G the armature.

Put on the shaft, and fasten up the bearings. Slack the button of the field magnet, and adjust it so that the armature will run freely, as near as possible to the end of the magnet without any chance of touching. Fasten on the brushes, one on each side of the shaft, and between the bearings; mind they touch nothing but the wood. Set the armature opposite the ends of the magnet, and bend the brushes so that they each press gently on the commutator. The dotted lines in Figs. 93 and 94 (pp. 102 and 103), show a position for the brushes, but their best place will be found after the model has been set going.

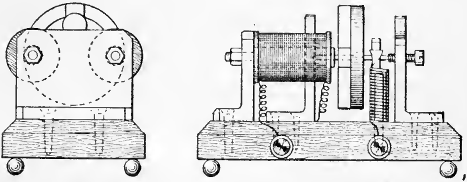


Fig. 96.—End Elevation. Fig. 97.—Side Elevation.

Figs. 96 and 97.—Miniature Electric Motor with Iron Yoke.

Now bring the ends of the wires from the brushes to the two first binding-screws, and the two ends of the field magnet coil to the other two. Let us number the four binding-screws from 1 to 4, Nos. 1 and 2 being connected to the two fore ends of the field magnets, and Nos. 3 and 4 to the two brushes. By connecting one pole of a battery to Nos. 1 and 3, and the other pole to Nos. 2 and 4, the armature and fields will be in parallel. In other words, if it were a dynamo, with a lamp where the battery is in the circuit, it would be said to be a shunt machine. If now, with a short length of spare wire, Nos. 2 and 3 be joined, and one pole of the battery connected to No. 1, and the other to No. 4, the armature and fields will be in series. Also by connecting Nos. 1

and 4 with a spare piece of wire, and the battery to Nos. 2 and 3, they will still be in series, but the current, not the motor, will be reversed—that is, if you have not turned the battery round, or placed the pole that was in No. 1 into No. 2, and the same the other side. Another way is to connect one cell to Nos. 1 and 2, and another cell to Nos. 3 and 4, then reverse the current in either Nos. 1 and 2, or Nos. 3 and 4, and the motor will be reversed.

Anyone who follows the foregoing instructions with a little care may have a small model electric motor at a merely nominal cost, the only expense being the copper wire, four small binding-screws, and some small wood screws; almost any kind of close-grained wood can be used for the stand. All the rest of the stuff, such as the iron, odd bits of copper, brass, etc., might be got from an old scrap-heap.

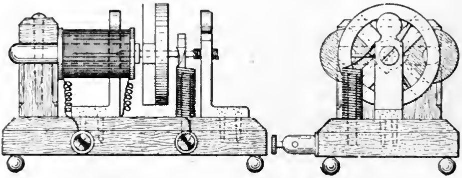


Fig. 98.—Side Elevation. Fig. 99.—End Elevation.

Figs. 98 and 99.—Small Motor, with Horse-shoe Magnet and Wooden Saddle.

Two other small motors are shown in Figs. 96 to 106. A fair-sized motor of this type, with a fly-wheel about $1\frac{1}{2}$ in. in diameter, will be found very handy to revolve small Geissler tubes, or to work small models. In the motor here described, the balance-wheel of a small round American clock was used for a fly-wheel, which is about $\frac{3}{4}$ in. in diameter. The drawings are all in proportion, so that a scale can be made, which will serve to work from.

Figs. 96 and 97 (p. 106), show an end and side elevation of the motor, with a small angle iron for a yoke, into which the magnet cores are either screwed or bolted. This method, of course, is the neatest, and will look the best; but as it necessitates the use of a few extra tools, nothing more will be mentioned about it, the drawings speaking for themselves. The simpler form, shown complete by Figs. 98, 99, and 100, will be followed; here a piece of round bent iron serves for a magnet, held in its place by a small wooden saddle and a button. In fact, the whole motor given in these three figures can be made from a few scraps of iron, brass, and wood.

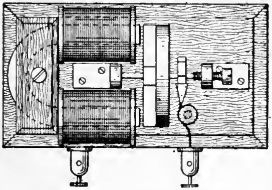


Fig. 100.—Plan of Small Motor.

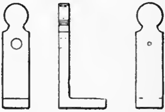


Fig. 101.—Bearing Brackets.

A piece of soft iron wire, $\frac{1}{8}$ in. in diameter, will make the magnet, bent to the form and proportions given in Fig. 103 (p. 110). Two little brown-paper bobbins, with very thin wooden ends, will be required, as in Fig. 102; fill these with No. 26 s.w.g. or No. 28 s.w.g. silk-covered copper wire. It does not matter at which end of the bobbins the wire ends come out as long as they are connected one with the other.

To connect the coils of the magnet, one end—it matters not which—will have to go direct to one of the binding-screws, and be clamped under it, while the other end has to be clamped under the foot of the back bearing bracket. The wire from the other binding-screw goes to the foot of the break spring (*see* Figs. 98 to 100).

Having made a little stand of polished or varnished wood, fix a small block at one end and clamp in the magnet and bobbins by means of a wood screw and a wooden button. Figs. 98 and 100 show this part of the fitting. The bearing brackets (Fig. 101) are cut out of sheet brass. The back one, between the bobbins of the magnet, has a small hole drilled half through it; the other carries a small screw with a hole drilled at its end; the two form point bearings for the fly-wheel spindle. These brackets should be fastened to the stand, so that the cross armature may revolve as close as possible to the poles of the electro-magnet without touching it (*see* Figs. 98 to 100). Two small binding-screws are fixed to the side of the stand (*see* Figs. 98 to 100); one end of the coil on the bobbins is fixed under one binding-screw, and the other end of the coil is fixed under the back bracket bearing.

Fig. 102.—Bobbin for Magnet Coils.

The most delicate part of this model is the contact spring, and as the machine is so small the pressure of this spring must be very slight indeed, although making good contact when required. One of the best methods of making this spring is to take a length of No. 24 S.W.G. or No. 22 S.W.G. silk-covered copper wire and bare about ¼ in. at one end; beat this out with a hammer, almost as thin as copper foil, cut the tip square, coil up the rest of the wire to form a spiral, and slip it loosely over a small wooden peg in the stand (*see* Figs. 98 to 100), fixing the bottom of the spring to the stand by means of a small spot of glue. The little flattened tip must be bent with a pair of pliers, so that it will just touch the tips of the teeth on the contact breaker, leaving them free whenever the arms of the armature are exactly opposite the poles of the magnet. The other end of this contact spring goes under the other binding-screw. All ends of wire are, of course, scraped clean and bright just before being clamped under binding-screws, etc.

The small armature is made of soft wrought iron, about $\frac{1}{16}$ in. thick, and must be cut to the shape shown in Fig. 104. File and trim it up true, and drill a hole through its centre to take the spindle or shaft. Tin the tips of the arms on one side; then, with a small copper bit, solder the tips to the rim of the balance-wheel.

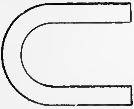


Fig. 103.—Horse-shoe Magnet.

Fig. 104.—Iron Armature.

The contact breaker for this size of motor should be about $\frac{1}{4}$ in. in diameter when finished. It is made from sheet brass, $\frac{1}{16}$ in. thick. Fig. 105 shows the method of setting out the four teeth, which can be cut with a small file. A hole must be carefully drilled through the centre and the contact breaker soldered to the shaft of the fly-wheel, as shown in Fig. 106, on the side opposite to the armature. After trimming all up, this completes the fly-wheel.

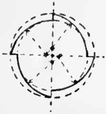


Fig. 105.—Setting-out Contact Breaker.

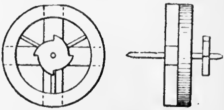


Fig. 106.—Fly-wheel Armature and Contact Breaker.

It is not necessary to describe how to make such small binding-screws as will be required; dealers sell them for about 1½d. each.

The model works by the current entering at one binding-screw, going round the coils of wire and making the core a magnet, which then attracts its armature. At the moment the armature is opposite the poles, the current is broken by the spring leaving a tooth on the contact breaker; the core immediately ceases to be magnetic, and allows the armature to proceed by the impetus given to the fly-wheel it is fastened to till the spring touches the next tooth, and so on.

A small dry cell will be the most convenient for driving the little model. One pole of the cell must be connected to one binding-screw, and the other pole to the other binding-screw. A small switch can be added to cut off the current and stop the motor; otherwise, one wire must be disconnected from one of the binding-screws.

A half-pint bichromate cell also will drive the little motor well, and for one charge from six to eight hours' work can be taken from it, either at odd times or at one run.

When the model is complete, for appearance sake it should be neatly painted with red sealing-wax varnish, black paint, or Brunswick black. Sealing-wax varnish is used so much for electrical models, etc., on account of its insulating properties, which are far above ordinary oil paints. The coils need not be painted; and unless special wire is bought, the silk on it will be green. Keeping all brass bright and showing the coils of green silk-covered wire will give a very pretty appearance to the model, which when made very small, is a taking little novelty.

CHAPTER IX.

HOW TO DETERMINE THE DIRECTION OF ROTATION OF A MOTOR.

In dealing with some of the principles on which electric motors act, we will take as an example the Siemens H-girder type. This form of motor has been chosen partly because of its simplicity of construction, partly as it is such a favourite form for small motors. In this chapter an endeavour will be made to make the principles clear by illustrating some of the laws that govern this type of machine, without in any way going into the subject of construction.

The principal law to understand is that governing what happens when a length of covered copper wire is wound round a bar of soft iron, and an electric current is passed through the wire. It is, of course, well known that the iron becomes a magnet, and remains a magnet as long as the current flows; but there are other laws of great importance to be considered.

Take a small bar of iron, as N S in Fig. 107; hold the end N in your left hand, and wind a length of covered copper wire upon the iron, beginning from your left hand and proceeding towards the other end, describing circles with your right hand in the same direction as the hands of a clock turn—that is, away from you on top of the iron, and towards you underneath. If you now pass an electric current through the wire coil, from the left-hand end to the right-hand end, as shown by the arrows—that is, if you connect the carbon plate of an active battery to the left hand, and the zinc plate to the right—the left-hand end of the iron becomes the north pole of a magnet, and the end that is at your right hand becomes the south pole.

Now take the iron bar, but wind it in the reverse way—that is, as you wind on the wire describe circles with your right hand in a direction contrary to that taken by the hands of a clock, as in Fig. 108—that is, pass the wire from you when going under the iron, and bring it towards you when coming over the top. Then send the current, as before, in at the left-hand end and out at the right, as shown by the arrows, and the poles will be reversed—that is, the north pole will be towards the right hand, N, and the south pole to the left, S.

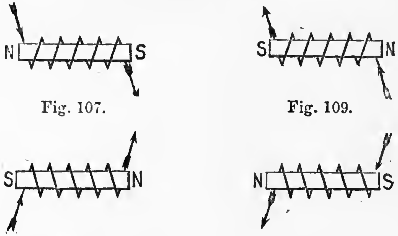


Fig. 107. Fig. 109.

Fig. 108. Fig. 110.

Figs. 107 to 110.—Directions of Currents and Resultant Magnetism in Bar Magnets.

Fig. 109 is wound in the same direction as Fig. 107, but the current flows, as shown by the arrows, from the right hand to the left; this will cause the poles to be reversed. Fig. 110 is wound in the same direction as Fig. 108; but by reversing the direction of the current, as shown by the arrows, the poles again become reversed, as occurred in the other case. This is what happens in a shuttle armature when the brushes cross the insulating strips of the commutator: the direction of magnetism set up in the armature by the armature current is reversed by the current being reversed.

A very good way to master this rule is to get a piece of wood, and mark one end "S" and the other end "N." Then get a piece of string; on one end tie a label, marked "+," or positive, on the other end tie another label marked "—," or negative. With the stick and the string practise the foregoing rule.

The next law to be understood is (*a*) if poles of the same kind are brought near each other, they will repel one another; (*b*) if two different poles are brought together, they will attract one another—that is, *north to north*, repulsion; *south to south*, repulsion; but *north to south*, attraction.

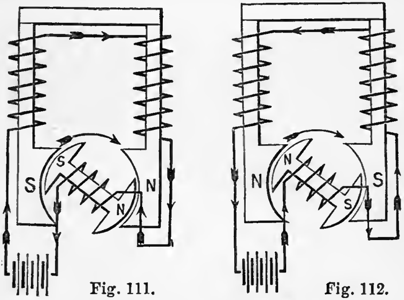


Fig. 111. Fig. 112.

Figs. 111 and 112.—Series Motors.

In the diagrams of motors (Figs. 111 to 116), the commutators and brushes have been left out in order to simplify the drawings. It must be understood that at the moment the two poles of the armature are opposite the two poles of the field magnet, the two brushes are resting upon the insulating strips of the commutator; immediately after that, as the armature rotates, the direction of the current is changed through the armature and its poles reversed. Though this is not the exact fact in practice, in this case we may assume it to be so.

In a motor of the Siemens type driven in series, the current passes either first round the magnets, then through the armature, and back to the battery, as in Fig. 111, or in the reverse direction, first through the armature, then the magnets, and back to the battery, as in Fig. 112. It may appear curious, but whichever way a current is sent through a series motor, as shown, it will rotate the same way.

Let us follow the winding in Fig. 111, starting from the battery. We will suppose that the direction of the current is as shown by the arrows. The first magnet core to be reached is the left-hand one; this, it will be observed, is wound as the iron bar in Figs. 108 and 110, and if the foregoing law has been understood, it will be seen that a south pole is left behind the winder. Crossing over to the other core, the winding is done as shown in Fig. 108, and this produces a north pole at N. After this the current goes to one brush, then through the commutator (these are not shown), and into the armature, wound in the same way as the bar in Fig. 109, which produces a north pole to the right and a south pole to the left. After this, the current again goes through the commutator, through the other brush, and so returns to the battery.

The position of the armature as shown in Fig. 111 is a little beyond the horizontal, so that the brushes are in contact with the commutator, and the current will flow through the whole machine. Now study what happens. The south pole of the armature is against or near the south pole of the magnet, and the north pole of the armature is near the north pole of the magnet. This means mutual repulsion, so the armature takes the motion indicated by the curved arrow above it, which, by the way, shows the direction of motion in all the diagrams. Influenced by repulsion, this motion continues until the south pole of the armature nears the north pole of the magnet; then, as they are of different poles, they will attract each other until the south pole of the armature has arrived exactly opposite the north pole of the magnet. At that moment the insulating strips cross the brushes and change the poles of the armature, and what was formerly the south pole in the armature now becomes its north pole, and like poles are again together and mutual repulsion is set up, causing a repetition of the same series of motions as has just been described.

If the battery current is now reversed, as shown in Fig. 112 (p. 114), and the winding is followed out, it will be found that every pole has been changed, so that again we have like poles to like, and the motion becomes the same as in Fig. 111. This means that if a motor is driven in series, it will turn in the same direction, whichever way the current goes.

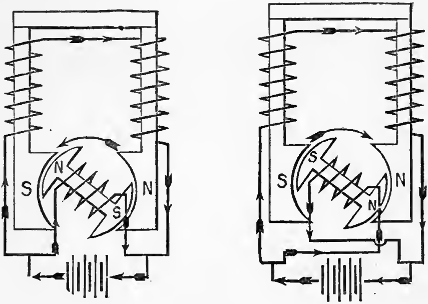


Fig. 113. Fig. 114.

Fig. 113 and 114.—Shunt Motors.

When a motor is driven as a shunt machine, the current from the battery is divided—part being shunted to the magnets and part to the armature. After the divided current has passed through the machine, it again unites in one wire and returns to the battery. By following the windings and the direction of the current in Fig. 113, it will be seen that the left-hand limb s is the same as s in Fig. 111 (p. 114), and that it is a south pole; the other must, of course, be a north pole, as the two limbs of the magnet are always wound so as to give opposite poles. Now follow out that branch of the current which passes through the armature; this will enter on the left-hand side and be wound with a coil going in the direction shown in Fig. 109 (p. 113); this will give a north pole to the left, and a south pole to the right. The current then goes through the commutator, etc., after which it joins the current round the magnet, and so returns to the battery.

In this case it will be seen that we have unlike poles near each other; these exert mutual attraction, and the armature rotates in the direction opposite to that shown in both Figs. 111 and 112 (p. 114).

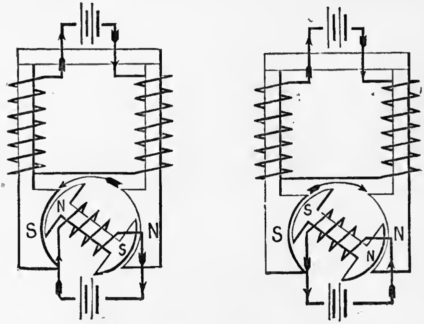


Fig. 115.　　　Fig. 116.

Figs. 115 and 116.—Motors driven with Two Batteries.

Now study what happens when the shunted part of the current is reversed through the armature, and the part of the current through the magnets is left as it was. Fig. 114 will show this. We have like poles together, exerting mutual repulsion, and the motion of the armature is reversed, turning in the same direction as shown in Figs. 111 and 112. We should also get a reversal by reversing the current round the magnet whilst keeping the current in the armature in the same direction as in Fig. 113 (p. 114).

For further study, suppose that the motor is driven with two batteries, one to excite the magnets and the other to excite the armature, as in Figs. 115 and 116. If now the windings and the direction of the current are followed out as in all the other cases, the direction in which the armature will move will be seen readily. Here, as was the case with the shunt motor, if the current is reversed in either the magnet or the armature, the direction in which the motor turns will be reversed.

Note that all the diagrams, from Fig. 111 to Fig. 116, are wound the same way; this has been done to show some of the different ways that one motor can be driven, by making different combinations with the current. But too much space would be required to show all combinations of winding and all combinations of current possible. As there are many more combinations than those shown, the reader will find it useful to sketch out a few skeleton diagrams, and put the windings and the currents in various ways different from these, and work out the motions himself.

As an example, supposing you have just bought the castings of a small model girder-motor, and that you wish to make it turn the reverse way to Figs. 111 and 112 (p. 114), when driven in series. Wind the magnet as in Figs. 111 and 112, but wind the armature as in Figs. 110 and 113; or, on the other hand, wind the armature as it is in Figs. 111 and 112, but reverse the twist in the magnet. Then you will have a motor that, when driven in series, will turn in the reverse direction to that shown in Figs. 111 and 112. All this is very simple—when once the law of winding a simple bar of iron has been mastered, and it is remembered that two like poles repel, and two unlike poles attract each other.

Finally, it must be said that it is always best to drive a motor with the current it was intended to take, and if it is desired to try experiments of this sort, rig up a motor specially for the purpose.

CHAPTER X.

HOW TO MAKE A SHUTTLE-ARMATURE MOTOR.

The small electro-motor shown in the accompanying illustration (Fig. 117) is suited to the requirements of those who have access to a lathe for turning certain parts. It is a machine that will look very well indeed if good workmanship is shown in the fitting and finishing of the various parts. But some careful fitting is required to make it run well. When properly made, it will drive a small polishing or dental lathe, or a small fretwork machine, or a small drilling-machine, or even a light sewing-machine, with a battery power of some three or four quart chromic acid cells, or the equivalent electrical energy from any other source.

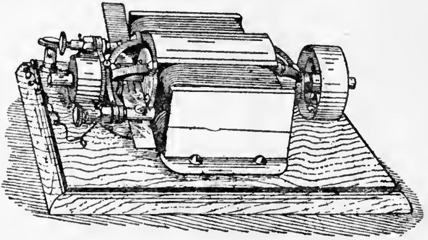


Fig. 117.—Shuttle-Armature Motor Complete.

The set of castings required consists of two malleable iron field magnet cores and bridges, as shown at Fig. 118, each measuring 4¼ in. in length by 2½ in. in width; one malleable iron casting (Fig. 119) for the armature, measuring $2\frac{1}{2}$ in. in length by $1\frac{3}{8}$ in. in diameter; two gun-metal castings, $1\frac{1}{2}$ in. in diameter (Fig. 120), for ends of the armature; two brass castings of four-legged spiders for the bearings of the spindle; one brass casting of a pulley, $1\frac{1}{2}$ in. diameter by $\frac{9}{16}$ in. thick; one brass casting of a collar, 1 in. diameter by $\frac{1}{2}$ in. thick; two brass end-pieces, $2\frac{9}{16}$ in. by $\frac{3}{4}$ in. (Fig. 121), to form feet for the field magnets; one brass casting for a brush rocker, $2\frac{1}{2}$ in. in length (Fig. 122); two brass castings of brush-holders (Fig. 123); two brass castings of set screws (Fig. 124); castings for the brass nuts, brass tube for commutator, and a strip of phosphor bronze for the brushes. These having been obtained, we will set about fitting and finishing the various parts and putting them together.

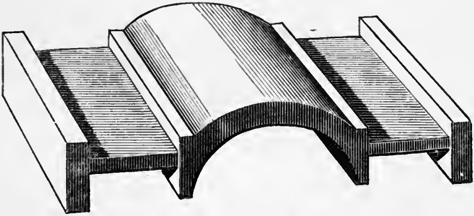


Fig. 118.—Field Magnet Casting for Shuttle-Armature Motor.

The field magnet castings, if rough, will require to be filed to make them fit and have a presentable appearance. All lumps should first be filed down with a flat bastard file. The channel for the armature must next be smoothed with a half-round file, care being taken not to do more than smooth the casting. The corners of the cores should be rounded off, to prevent them from cutting into the insulating cover of the wire as this is being wound on. The outsides may now be smoothed and the ends trued, to make the whole fit well together. The top casting for the field magnet is usually a little thicker than the under one. The under field magnet casting will have the two brass feet or holding-down pieces, shown at Fig. 121, fitted under each end, and must therefore have two holes drilled at each end. These receive two small screws, which pass through the brass feet and the lower casting into the top casting, as shown in Fig. 129 (p. 126). Small holes for set screws, to hold the feet of the spiders, must also be drilled and tapped in the corners of the armature channel, as shown at Fig. 129 ; these are fitted with round-headed brass screws. Thus prepared, the castings may have a coat of Japan black and be set aside to dry.

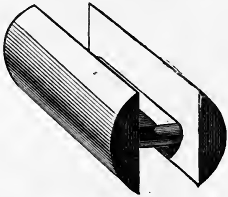


Fig. 119.—Armature Casting for Shuttle-Armature Motor.

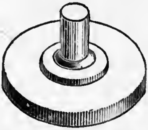


Fig. 120.—Gun-Metal Casting for Armature Ends.

The armature is of the Siemens H-girder type, in one casting of malleable soft iron. This must be filed smooth and true at the ends, and the channel must be made smooth with a file. The gun-metal end-pieces shown at

Fig. 120 will be fitted to the ends of the armature, to hold the steel spindles. These are made from two 2-in. lengths of $\frac{1}{4}$-in. steel rod, turned true and smooth down to $\frac{3}{16}$ in. diam. Turn the end-pieces smooth, drill a $\frac{3}{16}$ in. hole through the boss of each, and drive one end of each spindle into each boss.

The end-pieces will be secured to the ends of the armature, after being fitted true to it, by small brass screws; holes must therefore be drilled through the end-pieces and into the armature, which is tapped to receive the screws. In one of the end-pieces drill two extra holes for the ends of the armature coil to come through, and bush these holes with small tubes of ivory or bone. When the ends are fitted on, mount the armature in a lathe, and true it by turning away just enough to take off the rough skin. This done, mark all the screws and screw-holes to correspond, so that they can be identified when the machine is being put together. Take off the ends, and dress the web and channel with shellac or good sealing-wax varnish, then set aside to dry, ready for winding.

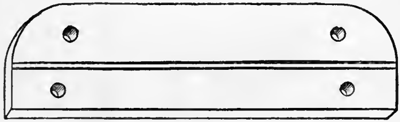


Fig. 121.—Gun-Metal Foot for Motor.

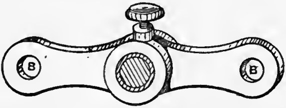


Fig. 122.—Rocker for Brush-Holders.

Brass castings as shown at Fig. 117 fulfil the double purpose of clamps to hold the field magnets together and of bearings for the armature spindles. These must now be drilled to fit the spindles, with holes in each foot to receive the holding studs, and with small oil holes for each bearing; then they must be filed smooth and neatly polished. The projecting boss of one of these bearings must be turned to form a bearing for the brush rocker (Fig. 122), which will fit on like a sleeve. The insides of the spider legs and bodies should also be turned smooth.

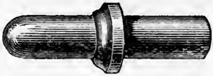


Fig. 123.—Casting for Brush-Holder.

The casting for the brush rocker is shown at Fig. 122. The hole in the centre must be bored to fit the boss on the bearing above-mentioned; and a hole must be drilled and tapped in the edge of the rocker to receive a set screw for fixing the rocker in any required position.

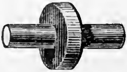


Fig. 124.—Casting for Milled Head Screw.

Two rough brass castings, as shown at Fig. 123, must be turned and filed to the form shown at Fig. 125 (p. 124), to form brush-holders, and these are held in holes, B B, drilled through the ends of the rocker (Fig 122). The holes in the ends of the rocker are drilled $\frac{5}{16}$ in. in diameter, and bushed with vulcanite or asbestos board, with a collar of the same on each side, to insulate the brush-holder from the rocker. A fairly good bush can be cut from a piece of rubber tube, with two collars of thin cloth to come between the shoulder of the brush-holder and the rocker on one side, and the nut and the rocker on the other; but indiarubber is liable to be destroyed by oil. In Fig. 125 the part B is first turned to $\frac{1}{4}$ in. diameter, and a thread chased on it to receive a brass nut. The plain part to the left of the chased thread must be drilled transversely with a $\frac{1}{16}$-in. hole, C, to receive the conducting wire, and this hole is met with another, E, drilled from the end, and tapped to receive a binding-screw with a milled head, as shown at Fig. 126.

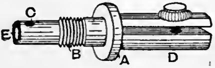


Fig. 125.—Brush-Holder complete.

Fig. 126.—Screw with Milled Head.

The other end of the brush-holder, D, is turned parallel, a slot $\frac{1}{32}$ in. wide is cut up to the shoulder A, one side of the holder is filed flat, and a $\frac{1}{16}$ in. hole is drilled through both jaws; the hole in one jaw is tapped to receive a brass screw, which passes freely through the other jaw.

The brushes are strips of phosphor bronze foil, 2 in. by $\frac{7}{16}$ in., cut to the form shown at Fig. 127. Six of these strips soldered together at one end form a pad. A slot, $\frac{1}{2}$ in. by $\frac{1}{8}$ in., is cut through the middle to receive the adjusting and tightening screw. There is a brush-holder (Fig. 125) at each end of the rocker, and in the jaws of this the brush is held.

Fig. 127.—Brush.

A two-part commutator, made of a brass ferrule split into two equal parts, will be required. On this form of armature there is only one coil, the two ends of which are connected to the two parts of the commutator. The brass tube which will be suitable for the castings has an internal diameter of $\frac{11}{16}$ in. This is fitted on a boxwood boss $\frac{5}{8}$ in. in width, bored with a hole which exactly fits the spindle at that end of the armature with the bushed holes in it. The ferrule is now to be scribed into two equal parts, and on each side of the dividing lines scribe two more lines, so as to have the three lines on each side ¼ in. apart. Through the centre of each of the two side lines drill small holes into the boxwood to receive brass screws, as shown in Fig. 128.

Countersink the mouths of these eight holes, and screw in the screws tight; then cut the ferrule into two equal parts with an oblique cut, as shown at Fig. 128. This is best done with a hack-saw, so as to make a clean cut through the brass and into the boxwood beneath it. The boss, with its split ferrule, is now pressed on the spindle with the inner ends of the oblique cuts adjusted so as to coincide with the wire holes in the armature ends.

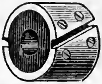


Fig. 128.—Commutator.

Winding the armature is a simple matter. Measure off 60 ft. of No. 20 S.W.G. double cotton-covered copper wire, roll it into a hank, and soak it for a quarter of an hour in melted paraffin wax, then hang it up to drain and cool. When cool, take the armature in the left hand, and the wire in the right. Place the commencing end of the coil with 2 in. left projecting at the left side of the channel, and hold it down with the left thumb whilst the wire is wound closely around the web of the armature in close regular turns, side by side, to the right side of the channel, then back again with the same care and regularity, until all the wire has been wound on in regular and even layers. Then twist the two ends together to keep the coil from unwinding. Test each layer for insulation as it is wound on, and test the whole coil again when complete.

The end-pieces may now be put on, then the ends of the armature coil may be brought out through the bushed holes in the casting and connected to the commutator. Each end of the wire should be soldered to the inner edge of one of the commutator pieces, along which they may lie to a length of ½ in. The coil may now be given a coat of sealing-wax varnish and then set aside to dry.

The field magnets must be so wound as to cause the pole above the armature to assume a magnetism of opposite polarity to that of the pole below the armature. It matters but little whether a north pole is at the top and a south pole at the bottom, or a south pole at the top and a north pole at the bottom, but they must not be both north poles or both south poles. The cores on the two sides of the arch must be wound in opposite directions. Thus, if we wind the left-hand core of the top magnet from left to right overhanded, we must wind the right-hand core from left to right underhanded. In commencing to wind the lower cores from the left-hand side, we must wind the left-hand core overhanded and the right-hand core underhanded. This ensures a south polarity to the lower pole, as shown in Fig. 129, if the current is sent through the wires in the direction shown by the arrows.

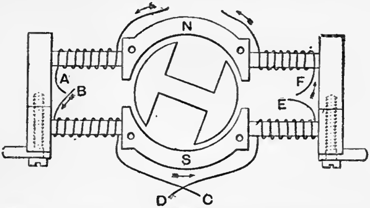


Fig. 129.—Section of Motor showing Winding.

Wind each core regularly with three layers of No. 20

S.W.G. double cotton-covered copper wire, and test each layer for insulation. When the last turn on each core has been reached, cut off the wire so as to leave 6 in. more than is needed to make the turn; pass this in under the turn of wire so as to form a kind of half-hitch, and draw it tight to prevent the wire from unwinding; then give the whole a dressing of sealing-wax varnish to secure each coil in its place, and to give the whole a finished appearance.

When the machine is being put together, the coils must be connected as here described, and shown at Fig. 129. The finishing end of the first coil at A must be bared of the cotton covering and cleaned; so also must the commencing end of the second coil on the next core at B. Dip both cleaned ends into some soldering fluid, tin them with a hot soldering-bit, twist the tinned ends together with a pair of pliers, then give them a final touch with the soldering-bit to fuse the solder and unite them. Each end must be thus treated and connected, namely, A to B, C to D, and E to F. The two ends C D may be passed down holes made in the base of the motor, and connected beneath. The two free ends above the upper pole will then go, one to one of the brushes, and the other to one of the terminal binding-screws on the base, if the coils are to be connected in series with the armature; or both will be connected to the brushes if the coils are to be connected in parallel with the coil on the armature, so as to make a shunt motor.

When fitting the parts together, the field magnets may be fitted first, the ends of the coils soldered and tucked in out of sight, the screws holding the two cores inserted and screwed tight, and the brass feet screwed on. Next, fit the already turned and polished spider-bearing to the end opposite to that on which the commutator is fixed. Then put in the armature, slip the other bearing on its spindle, and screw this bearing in its place. Now turn the armature round by hand, and see that it runs truly in the tunnel, not touching anywhere, but equidistant from the sides at all parts. The back pulley (*see* Fig. 117, p. 119) should now be fitted on the spindle, and tightened on it by means of a small set screw passing through the boss on the outside. The rocker may next be fitted on, and secured to the outside of the bearing by a small set screw. One of the brushes will have its free end bearing on the top of the commutator, and the other brush will press lightly against the under-side of the commutator.

The brushes B, brush-holders H, and rocker R, complete, are shown in Fig. 130. The exact position of the brushes

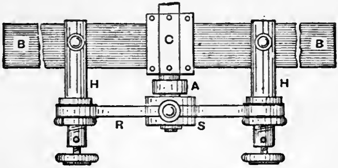


Fig. 130.—Brush-Holders, Rocker, and Brushes complete.

will be determined by the direction of rotation of the armature, the commutator running away from the brushes. The correct angle to set these must be found by experiment. The rocker can easily be moved until the best effect has been obtained, then fixed in this position by the set screw. The collar is now slipped on the spindle, the armature brought forward until it runs free in its proper position, and the collar tightened to prevent undue end shake of the spindle in its bearings. A little end play or shake is always admissible, but side shake, due to loose fitting in the bearings, must never be allowed. The motor may now be mounted on a base made of oak, teak, or mahogany, and furnished with brass terminals to the wire coils, as shown at Fig. 117 (p. 119). The insulation of the wires on the field and armature may be tested in the manner described in Chapter VII.

CHAPTER XI.

FIFTY-WATT UNDERTYPE DYNAMO AND MOTOR.

The following figures show a dynamo which will either light three 10-volt 5-candle-power lamps, or work well as a motor when supplied with current from a battery. The illustrations are all to a scale of one-half full size, and dimensions may be measured from them. Assuming that the castings and other materials are ready, it will be convenient to consider the work of construction in three divisions—first, mechanical construction; second, insulation; third, winding on the wire and connecting up.

Commence with fitting up the brackets and armature; the holes for the shaft must be drilled on the bearings A, A, Figs. 131 and 132 (pp. 132 and 133); at each end of the boss, punch a centre in the middle of the round part of the top of the bearing. The hole should be drilled rather less than $\frac{1}{4}$ in. diameter, a little way in from one end first, then reverse the bearing, and drill up a little from the other end, reverse again, and so on until the holes meet at about the middle. The oil cups B, B, Fig. 132, can be drilled as shown, the hole at the bottom, about $\frac{1}{16}$ in. diameter, being drilled through into the bearing-hole to allow oil to pass. Drilled thus, the holes for the bearing will be found to be somewhat rough and perhaps not exactly in line; this will be remedied by a reamer or rose-bit passed carefully through. Use a little oil as lubricant, and work from one end only. If the drilling has been carefully done with a drill about $\frac{1}{32}$ in. less than the finished size the hole will be reamed quite smooth. Care must be taken not to spoil the bearing surfaces when handling the castings for other operations.

The bore of the field-magnet casting, Figs. 133 and 136, if well cast will be very nearly a true circle; it should be cleaned out with a file to remove any lumps or irregularities. To take a cut through with a boring bar on the lathe makes the best job, but good results may be obtained without this if a good casting is secured. To get the bearings in alignment a dummy armature and shaft must now be made. Get a piece of iron or steel rod just the length of the armature shaft and of a convenient diameter, such as $\frac{3}{8}$ in., and on this mount tightly a piece of hard wood, about $1\frac{3}{4}$ in. diameter, of the length the armature core will be, and in the same position. Turn the wood to fit tightly in the bore of field-magnet, and turn the rod also at each end to fit the bearings. Place the dummy tight in the bore, slip the bearing castings on the spindle, and fit the end lugs D, Fig. 132, to bed flat on the sides of the field-magnet; if they are much out, the castings may be hammered until they are somewhere near right, and the final adjustment effected with the file. A little red ochre mixed with oil and smeared on the magnet will show where the lugs touch. It is important that these brackets should bed properly, or they will not be in line when screwed in place, and the shaft will run stiffly.

The holes for the screws E, Figs. 132 and 133, may be drilled in the bearing castings; then slip the bearings on the dummy shaft and mark the field-magnet by drawing the point of a scriber round the holes in the castings. Some chalk rubbed on the magnet where the bearings come will assist to show the line. Tapping holes for $\frac{3}{16}$-in. screws may be drilled about $\frac{5}{8}$ in. deep in the centres of the marked circles. Mark off holes in the field magnet feet for the holding-down screws, the positions being taken from the drawing (*see* F, Fig. 131). The diameter of the holes may be about $\frac{1}{4}$ in., chamfered to suit the wood screws intended to be used.

The armature, Figs. 134 and 135, is now to be made; its shaft is of steel $7\frac{3}{4}$ in. long; if made from rod that is quite straight and true, the diameter can be $\frac{5}{16}$ in., so that the central portion need not be turned; but it is better to have the diameter $\frac{3}{8}$ in., and take a light cut all along, reducing to $\frac{5}{16}$ in. diameter. At the pulley end a length of $1\frac{1}{2}$ in. has to be turned down to form the bearing, and at the commutator end a length of $2\frac{1}{8}$ in. These necks should be left a little large, so that they can be fitted in after the core discs H, Fig. 135 (p. 138), are tightened up in place, the screwing up of the clamping nuts J having a tendency to bend the shaft. The screwed portions for the clamping nuts are cut as shown, for about $\frac{7}{8}$ in. at each end; a screw with about twenty threads to the inch is necessary, and is best cut on a screw-cutting lathe; but if this is not available, the thread may be started with stock and dies and finished with a comb chaser.

About 120 core discs, about $\frac{1}{50}$ in. thick, must now be prepared. The central holes must pass over the shaft easily; any burrs must be filed off, for if not flat the screwing-up of the nuts will cause uneven parts to bend the shaft. In the middle of the core is the circular groove K, Fig. 134, $\frac{1}{4}$ in. long, to take the binding cord. To make this, a few discs should be reduced in diameter and put on the shaft when half the other discs are on. It is a difficult job to turn out this groove on the lathe if left till the core is complete. Before threading the discs on the shaft one side of each should be painted with a thin coat of enamel or Brunswick black and left to dry. The clamping nuts J, Fig. 134 (p. 138), are circular pieces of brass $\frac{3}{4}$ in. diameter, with a hole in the centre drilled and tapped $\frac{5}{16}$ in. to fit the screwed shaft. The side of the nut which is to go next to the discs should be faced up true on a screw mandrel, and the outside corner rounded off as shown in the drawing. Two parallel flats are filed on the edge (*see* Fig. 135, p. 138) to take a spanner.

Put the core discs on the shaft, the painted sides all facing one way; see that the core is in the right position lengthways on the shaft, and that the channel L, Fig. 135, for the insulated wire is straight; then screw up the nuts as tight as possible, leaving the flats flush with the channel; a little oil between the face of the nut and end disc assists. Test the shaft between

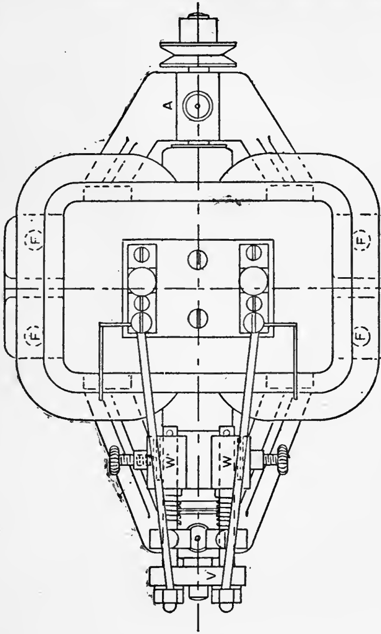


Fig. 131.—Plan of Dynamo (Half Scale).

centres, and, if required, straighten it; then turn down the necks to fit the bearings. When a good fit is attained, place the armature in the field magnet and fix the brackets in place. The armature should be central in the bore and should spin freely with the fingers; if stiff, ease the shaft bearings until it runs freely and yet without shake. An end movement of about $\frac{1}{16}$ in. is advisable. The armature core should coincide lengthways with the field magnet; should it project from one side more than the other, the magnet will try to pull it into a central position. In doing this it pulls against a bearing, which will have a tendency to get hot. Any of the core plates that project can be levelled down with a file.

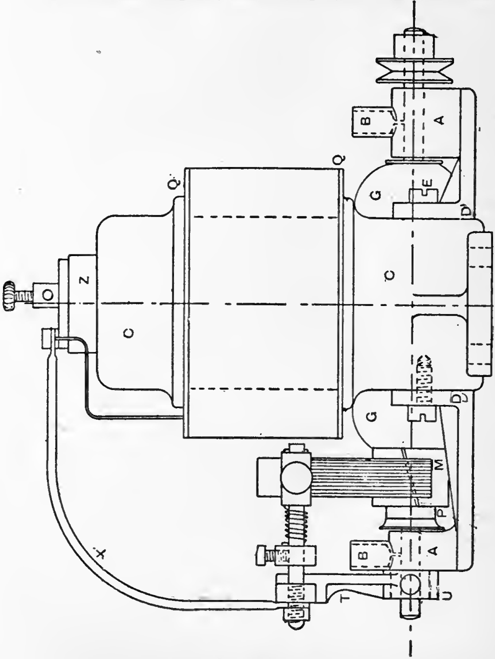


Fig. 132.—Side View of Dynamo and Motor.

The commutator consists of a piece of brass tube M,

Fig. 134, fixed on a wooden bush and carried on the armature shaft. The brass tube is divided into two equal segments by saw-cuts nearly parallel to the axis of the shaft, one portion being connected to one end of the armature wire and the other portion to the other. It is essential that the two portions must not be in metallic communication except through the armature wire, and the segments must not be in metallic communication with the shaft. The commutator may be a piece of seamless drawn tube, and should be a little over 1 in. outside diameter and ¾ in. long. The thickness may be about ⅛ in., so as to allow for truing the surface from time to time as it becomes worn by the brushes. The hardwood insulating bush o, Fig. 134, will be ⅞ in. long. Through its centre drill the hole for the armature shaft, using the same drill as for the bearings, and ream it out to fit tightly on the shaft. It is best to use a mandrel to turn the bush on, and when this has been done the tube should be fixed with cement and left to set. The bush must project ⅛ in. at the end nearest the bearing. Mark off centres for two holes in the tube at diametrically opposite points for the screws which are to hold the commutator segments to the bush. These holes may be ⅛ in. diam. countersunk into the tube, so that the screw-heads will come nearly flush, just leaving enough projecting to quite fill the hole up when the outside of the tube has been turned true. These screws should be of brass, and must fit tightly, or when turning up the commutator they will come loose. It is very important to have these screws short, so as not to touch the shaft, as there must be no metallic connection between the tube and the shaft.

Mark on the tube two diametrically opposite lines running from one end to the other midway between the screws just put in. These lines are to locate the positions for the cuts P, Fig. 132 (p. 133), which separate the tube into equal parts. These cuts are sawn about $\frac{1}{32}$ in. wide, and aslant, as shown in Fig. 128 (p. 125); this causes the brushes to pass from one segment to the other gradually, and lessens the sparking and wear. The amount of slant is not important; a deviation of about $\frac{1}{16}$ in. each side of the centre line will do. Saw down to the bush and slightly into it, so as to separate the segments completely; see that the slot is perfectly clear of cuttings; and to keep the segments apart and prevent dust from getting into the slot, insert a thin strip of wood or mica. A little cement or shellac varnish will keep it in place. In each brass segment, at the end next to the armature core, saw a nick just large enough to allow the ends of the armature wire to go in and fit tightly. The complete commutator may now be gently driven on the shaft, the slots being in line with the round part of the core, as shown by Fig. 137 (p. 142)—that is, at right angles to the centre of channel L, Fig. 135 (p. 138).

The oil-guard R, Fig. 133, can be of brass, and is driven tight on the shaft after the commutator is in place. The oil-guards for the pulley ends can be tapped to fit the screwed part of the shaft, or made to fit the plain part, and can be put in place after the armature is wound.

To fit up the brush gear, Figs. 131, 132, and 133, commence with the rocker T, Fig. 132 (p. 132). This allows the brushes to be moved round the commutator in order to find the position which gives best results when working. Bore a hole about $\frac{1}{2}$ in. in diameter in the boss U to fit on to the boss on the bracket, so that the arm is straight and square with the hole. Put the rocker on a mandrel and face each side of the boss. Now put the bearing bracket on a mandrel, and turn down the projecting boss to fit the hole in the rocker. The small boss at the side of the rocker is to take a set-screw, as shown in Fig. 132; this screw should fit in the thread. A piece of hard wood is required for the crosspiece to carry the brush-pins (*see* V, Fig. 131). This should be filed up about $1\frac{1}{4}$ in. by $\frac{1}{2}$ in. by $\frac{1}{4}$ in. thick; the angle to receive it must be filed out square to the hole in boss, so that when the crosspiece is fixed in, the pins will come parallel to the shaft. Mark the exact centre of the crosspiece, and drill a hole to clear a countersunk screw ⅛ in. diameter. Now place the crosspiece in position in the angle of the rocker arm, so that it projects equally at each side, and with a scriber mark off on the

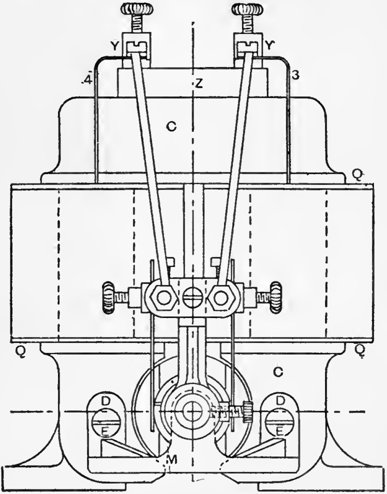


Fig. 133.—End View of Dynamo.

brass the position of the hole; drill and tap it to fit the screw. The crosspiece can now be fixed in place. At ¾ in. on each side of the middle, mark centres for the brush-pins, on the centre line of the crosspiece, and drill and tap two holes $\frac{3}{16}$ in diameter.

The brush-holders w, Fig. 131 (p. 132), must be finished next. The castings should be filed all over, and the ends squared. Mark the centre at one end of the circular part of the casting, and drill a $\frac{3}{16}$-in. hole through it. The slots for the brushes can be cut from one end with a saw, as shown dotted in Fig. 131. They should be $\frac{9}{16}$ in. long fully $\frac{1}{16}$ in. wide, and parallel with the holes already drilled. Drill and tap the bosses for $\frac{1}{8}$-in. diameter clamping screws, as shown. These bosses may be turned by putting a small mandrel in the screw-holes before they are tapped and holding the mandrel in a chuck. To make the pins, if straight $\frac{3}{16}$-in. brass rods are chosen to fit the holes in the brush-holders they will only need to be polished. Screw one end of each pin for a length of $\frac{9}{16}$ in., and at the other end drill a small hole through the diameter. In this hole place a pin to prevent the brush-holder from being forced off by the spring. The pins can now be screwed tightly in place in the cross-arm. Make two hexagonal nuts to screw on the threaded part which projects through the cross-arm; these are to clamp the flexible wires X, Fig. 132, which carry current to the terminals. For adjusting the tension on the springs, two collars, as shown, are required. They may be made from $\frac{5}{8}$-in. brass rods, drilled to fit the pins, and each should be fitted with a set-screw to fix it in the required position. A small hole is drilled in the face at one side of each collar to take one end of the spring, and a similar hole should be drilled at the end in each brush-holder to take the other end of the spring. The spiral springs are made of hard brass wire, about No. 24 S.W.G.; one is coiled left-handed, and the other right-handed.

The terminal blocks Y, Fig. 133, are filed all over and polished, and holes are drilled and countersunk to take wood screws, which hold the blocks down on the terminal-board. A hole is drilled and tapped in each block at the end next the commutator to take $\frac{1}{8}$-in. cheese-head screws, which clamp the field-wires and brush-wires (*see* Fig. 131). Holes are drilled through the upright blocks to receive the outer-circuit wires which are held by set-screws put in from the top.

The terminal-board Z, Figs. 132 and 133, can be made from a piece of mahogany about $1\frac{1}{4}$ in. by 2 in. by $\frac{3}{8}$ in. thick, and polished or varnished according to taste. Holes are drilled in it to take two $\frac{3}{16}$-in. countersunk screws, which fix the board to the field magnet. The holes in the magnet should be drilled and

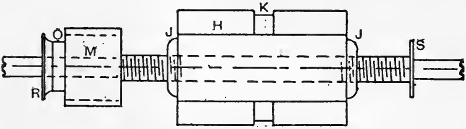


Fig. 134.—Armature (Side View).

tapped last, and marked off for position from the terminal-board.

The driving pulley (shown in Figs. 132 and 133) may be made suitable for either a flat or a round belt, and of dimensions to suit the manner of driving. If the dynamo is to be driven from a foot lathe or hand wheel, a pulley about 1 in. diameter over all is a convenient

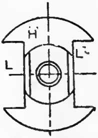


Fig. 135.—Armature (End View).

size, with a V groove to take round belt of $\frac{3}{16}$ in. diameter. The width of the pulley should be about $\frac{5}{8}$ in., and it can be bored with a tapering hole to fit a taper shaft, or hole and shaft can be made parallel, and a set-screw put in the boss will hold them together. The fit should be good; and when the armature has been put between centres and the pulley finally turned true in its place, the mechanical construction is finished.

To proceed with the insulation. Take the armature out and the bearings off. Examine the field magnet where the wire is to be wound, and with a file smooth off all corners, any rough places, and all sharp edges and points likley to cut through the insulation. Wrap two layers of thick brown paper round each core, sticking them on with shellac varnish. Cut out four rectangular cardboard cheeks or flanges Q, Figs. 132 and 133, to fit the cores; the wire will extend about $\frac{5}{8}$ in. from the core, so the cheeks must be made to suit; they can be sprung on the cores if a slanting cut is made across one side and a piece of paper is pasted over the cut to keep it together when the cheeks have been pushed to their places at the ends of the core. Carefully look over the insulation and see that it is sound everywhere, so that the wire cannot come into contact with the iron at any point. Then brush a thick coat of shellac over the paper wrapping and cheeks, and leave them until quite dry.

The armature must be treated in a similar way. Smooth all projecting points, edges, and corners along the channel where the wire is to be wound; then with a single layer of thick brown paper cover the channel, the ends of the core, and the shaft to the oil-guard at the pulley end and to the commutator at the other end. Leave the paper projecting a little beyond the edges of the channel, so as to be sure that the insulation comes up to the edges; it can be trimmed down after the wire is wound on. The edges at the ends of the channel can have an extra thickness of paper put on over the first covering, as the covering on the wire is liable to be cut through at these points. Examine the insulation; if all right, give it a thick coat of shellac and leave to dry.

To wind the field-magnet requires about 2 lbs. of No. 22 S.W.G. single cotton-covered copper wire, which may be wound, layer by layer, by hand, in the direction shown in Fig. 136, keeping it as even as possible with a moderate tension. The number of layers is not important, and the winding may be finished either at the top or bottom. It does not matter greatly if the number of layers on each core is not quite the same; try to put about 1 lb. of wire on each core; but it is essential for the winding to be in the direction shown in Fig. 136, and kept so throughout. As each layer is finished it should be brushed all over with sufficient shellac varnish to give the surface a good coat. The commencing ends of the wire B and A, Fig. 136, which reach from the core outwards, should be wrapped round with thin paper along the part which is buried in the end of the coil, and varnished with shellac to make sure that the current goes straight to the innermost layer and does not leak away to the other layers. The current must go through the wire from end to end without making a short cut across at any point. If a bare or frayed place is found while winding, cover it with some thin paper. The most convenient way to wind the coils is to fix a strip of wood to the top of the magnet by the terminal-board screws, and then to fasten the wood to a face-plate fixed on the lathe, bringing each core in turn to the centre. If the weight of the overhanging core is counterbalanced, the magnet will be rotated more conveniently; turn the face-plate round with the left hand, guiding on the wire with the right hand, assisted by the left where the wire requires passing between the cores. The magnet may be made with a joint through the top to allow of winding the coils in the lathe, if the joint is made to be in close contact all over the surface. The extra trouble taken to wind the coils as described is nothing compared with extra work needful to construct the joint and magnet in one piece in the way mentioned. Completely wind one core first to the full depth of the cheeks, and then proceed with the other, joining the ends to make the final connections. Cover the last layer with two or three coats of shellac varnish.

To wind the armature requires about ¼ lb. of No. 20 S.W.G. double cotton-covered copper wire. Put the armature in the lathe between centres, with the commutator to the right hand. Commence from the right-hand end and lay the wire from there, along the channel to the left-hand end, then across the end and underneath along the channel to the right-hand end, across the channel for one layer, then back again for second layer. Get on as much wire as possible, and continue winding until the channel is quite full.

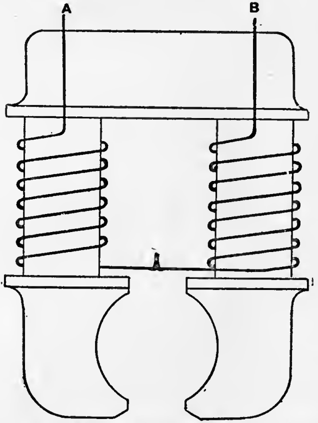


Fig. 136.—Field Magnets, showing Method of Winding.

Each layer of wire should have a coat of shellac varnish. If found more convenient, the portion of the channel on one side of the shaft may be filled up first and then that on the other side. Having commenced to wind the wire round the core in a certain direction, this direction must be maintained right through, as is shown by Fig. 25 (p. 23). It is easy to reverse the direction of the winding when passing from one side of the shaft to the other, and care must be taken to avoid this mistake.

The wire being all wound, bind it tightly with strong thin cord wrapped round the centre groove of the core K, Fig. 134, prepared to receive it. This makes an even binding about ¼ in. long, and it prevents the wires swaying outwards owing to centrifugal force when the armature is rotating. The beginning and the finishing ends of the wire on the armature must now be connected to the commutator. One end goes to each segment, and both must be soldered into the nicks made for them; it is well also to bind some cord round these wires to keep them in place. When all is finished, give the wire and binding cord a thick coat of shellac.

The commutator can now be finally trued up in the lathe, taking a very light cut, to remove any surplus solder and to make it run quite true. Put a disc of thin card between the pulley-end oil-guard and the armature wire, to prevent any chance of damaging the insulation.

Fig. 137.—Position of Commutator on Armature.

The dynamo can now be finally put together. The field-wires are connected up to the terminal blocks as shown in Figs. 132, 133, and 134, and also joined together in the centre as shown in Fig. 136. This last joint should be twisted and soldered to make good contact. Connect the brush-holder pins by flexible copper wires to the terminal blocks, so that the rocker may be easily moved. These flexible wires are made by coiling some No. 20 S.W.G. insulated wire on a rod $\frac{3}{16}$ in. diameter, just as spiral springs are made; enough of the wire at each end is stripped of its covering to make contact with the clamping screws.

The brushes may be made of sheet copper or of copper wire; they should be flexible, to make good contact with the commutator and brush-holders. A good brush may be made from copper wire, about No. 24 s.w.g.; fix one end in a vice, take hold of the other end with a pair of pliers and give a fair pull, to stretch the wire a little and straighten it. Cut off sufficient pieces, each 2 in. long, to make two brushes each ½ in. wide, and at one end solder the wires together. It is a good plan to curve the brush where it touches the commutator, so that there is a surface of contact about ⅛ in. broad all along the brush.

The dynamo is now complete, but, to commence with, its field magnet requires exciting; afterwards it will always excite itself. The direction for running is that of the hands of a clock, when the observer looks at the side of the pulley as if looking at a clock face. Rotate the armature in this direction at a high speed; if it suddenly works stiffly and sparks appear at the brushes, it has started itself all right, and the field magnet will not require any further assistance; but if this does not occur, and the dynamo fails to light a 10-volt lamp, an electric battery will be required to give the field magnet the necessary start. Put a piece of paper between one of the brushes and the commutator to prevent the current going through the armature. Now, looking from the commutator end, connect the positive wire of a strong battery to the right-hand terminal, and the negative wire to the left-hand terminal. While the battery is thus connected, gently tap the iron of the field magnet with a hammer for half a minute; disconnect the battery, remove the paper from under the brush, and on driving the armature again the machine should work all right. The output of this dynamo, with 3,000 revolutions per minute, is about 10 volts at 5 ampères; but it will give higher electro-motive forces up to about 20 volts with less current if run at higher speeds. The dynamo can be painted to suit taste.

CHAPTER XII.

440-WATT MANCHESTER TYPE DYNAMO.

THE dynamo described in this chapter is of the Manchester type, shunt wound, and designed for an output of 440 watts—viz. 8 ampères at 55 volts—when running at 1,800 revolutions per minute. Figs. 138 and 139 (pp. 145 and 147) show a plan and an end view of the machine complete.

The field magnet castings can be bought with the armature tunnel bored out, $5\frac{1}{8}$ in. diameter, and the field magnet cores fitted. The base of each pedestal is turned, making the centring of the armature in the tunnel much easier than when a flat-bottomed pedestal is used. The field magnet cores, $2\frac{5}{8}$ in. diameter and $5\frac{1}{4}$ in. long, are wound with 11 lb. of No. 20 S.W.G. cotton-covered wire—$5\frac{1}{2}$ lb. being wound on each core. The direction of the winding is shown in Fig. 141 (p. 151), producing a north pole at the top and a south pole at the bottom.

The field-magnet bobbin ends may be fixed by turning a shoulder on each end and shrinking on these shoulders circular plates of iron $\frac{3}{16}$ in. in thickness. But if unable to turn these shoulders, the bobbin ends may be made of either sheet brass, sheet vulcanite $\frac{3}{16}$ in. thick, or thin hard wood. To make wood ends, procure eight sheets, each $\frac{1}{8}$ in. thick, by 6 in. square, of any close-grained hard fretworking wood, such as pear, holly, walnut. Glue pairs of the sheets together face to face, with the grain of one running at right angles to the grain of the other, and cramp them in a flat press for twenty-four hours, thus making four sheets $\frac{1}{4}$ in. thick. Then screw the four sheets together at their corners, mount them on the face-plate of a lathe, and in the centre bore a hole to fit the magnet cores tightly. Turn the outside to make a disc 5 in. diameter, and thus make the bobbin ends.

The cores of the field magnet are drilled at each end, and tapped ½ in. A stud 3 in. long is screwed into one end, and in the other end place a hexagon-headed bolt 3 in. long. Centre the end of the stud and the bolt head, and place the core between the lathe centres to see that it runs fairly true. Then paint the core with Brunswick black, and, while wet, push the bobbin ends on and paint them on the inside and round the joint. The ends of the cores must be left clean and bright, otherwise they will make a bad joint with the pole-pieces, and so lower the efficiency of the dynamo.

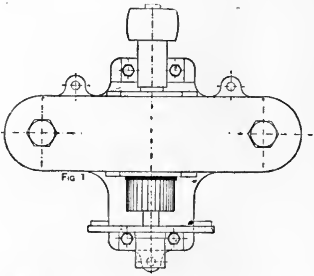


Fig. 138.—Plan of Manchester Dynamo.

Winding the wire direct on the core would tend to force off the bobbin ends. Pieces of wood ½ in. thick and 5 in. square, with holes in the centre to pass over both the stud and the bolt, and pressed against the ends of the cores by two ½-in. nuts, will prevent this. The wire can be wound on evenly by hand in the lathe, using a very slow speed. It should previously be coiled, and placed so that it may run freely ; and can then be run through the hand without causing kinks. An empty bobbin held in the palm of the hand, for the wire to run over, will avoid making the fingers sore.

A coat of shellac varnish should be given each layer, and allowed to dry; then wind back, and so continue until all the wire is wound on. When both cores are wound, put them in a warm place for a few hours to dry and harden.

The armature is 5 in. diameter and 4 in. wide, and is built up of 150 soft iron cog-ring stampings, having ten channels 1 in. wide and ½ in. deep. An easy method of insulating the laminations is to cut 150 sheets of tissue paper 6 in. square, and with shellac varnish paste a sheet on each stamping. Then thread the stampings together with five brass rods ¼ in. diameter and 5 in. long, screwed each end for ⅜ in. Put washers on the brass rods to equal the thickness of the bosses on the spider arms, and screw up the end nuts until the armature is 4 in. wide, using the calipers to ascertain that the end faces are parallel.

Fig. 140 (p. 149) shows a section through the spiders. The outside is comparatively flat, and the inside has a central boss and also smaller bosses near the end of each arm. A circle 4½ in. diameter ought to bisect each boss on the end of the five arms. In the centre of each boss drill a ¼-in. hole to receive the ends of the brass rods. If the rods do not enter their respective holes, the spider arms may be bent by light blows with a hammer.

When the spiders are bolted on the armature, run it between the lathe centres, and adjust centre dots placed in the spiders till the whole runs true. Having marked the position of the spiders, take them off and bore a ⅞-in. hole in the central boss of each. Decide which one is going to be placed at the commutator end, and in it file a keyway ¼ in. wide and $\frac{3}{16}$ in. deep; this should be under one of the arms, so as to weaken the spider least.

The steel spindle is shown at Fig. 140 (p. 149); it is 14⅜ in. long, its collar being 1⅛ in. by ¼ in. The central portion is ⅞ in. diameter by 7⅜ in. long, the journals being

11/16 in. diameter by 2½ in. long. The keyway must be cut at the commutator end ⅛ in. deep and ¼ in. wide for a length of 3½ in. A keyway 3/16 in. wide and deep must also be cut at the pulley end.

The bearings are of cast iron, and their bases have the same radius as that of the armature tunnel, the bearing steps being turned and the tunnel bored at the same operation. The web of the bearing stands outwards when in position. Bore each bearing to take the shaft, and, at the inner side of the bearing at the commutator end, turn a shoulder 1¼ in. diameter and ½ in. wide to take the brush rocker. In the top of each bearing drill and tap an ⅛-in. gas-thread hole for a lubricator. Mount the bearings together on a mandrel, and turn up their bases. They are fixed with ⅜-in. bolts. The height for the bearings may be found by trying the armature when it is mounted on the shaft, to see that the air space is equal above and below.

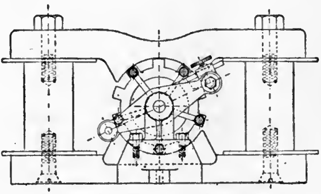


Fig. 139.—End View of Dynamo.

The cast-iron driving pulley is 2½ in. diameter by 1¾ in. across the face. It should be bored to ⅝ in., and fastened to the shaft with a key 3/16 in. wide. The depth of the slot in the pulley should be ⅛ in. This key must have a head, so that it can be drawn when required.

File or turn three grooves ⅜ in. wide and 1/16 in. deep round the armature stampings, to take binding wire, as explained on p. 54, one groove in the centre and the other two 1 in. from each end of the armature. Sinking the binding wire into the iron core allows a margin for wear in the bearings, and gives a small air space, thus tending to make the machine more efficient.

Carefully remove all sharp corners from the armature, as if the stampings cut the insulation of the wire the whole coil has to be unwound, the insulation repaired, and finally the coil rewound, which may take hours to complete. The whole of the armature should now have a coating of shellac varnish. When an assistant is to help wind the armature, the shaft and spiders are removed; it is then laid on a trestle and held firmly down by a strip of wood passed through the core. For a single-handed job, fasten it down to a table, as shown on p. 68, so that it will thus be possible to work at it sideways, and get at each end.

Before winding the wire the channels must be covered with paraffin-soaked tape, one layer being sufficient; as a further protection, an extra strip of narrow tape may be put across each of the corners.

The wire, consisting of 5 lb. of No. 17 S.W.G. double-cotton-covered, must be divided into ten equal lengths. To do this, fix two empty cotton-reels at a distance of 45 ft. apart; then fasten one end of the coil to one reel, and wind the wire backwards and forwards round each reel until the whole coil is unwound. The wire so wound should consist of ten lengths, but if there is any short or over, measure it and shift the reels apart so that all the wire is used in ten turns round the two reels. Then cut the wires where they pass round the reels, and produce ten equal lengths. By placing the reels at half the distance apart and cutting at one end only, the same result is to be obtained. Each length must be loosely coiled, soaked in melted paraffin wax, and allowed to drain and harden. Proceed to wind one of these coils on a wooden shuttle, 24 in. long, 1½ in. wide, and ⅜ in. thick, the ends being hollowed out like a butcher's tray (*see* Fig. 58, p. 52). Cut from hard wood ten pieces, ½ in. square and 1¾ in. long, with a ¼-in. hole drilled $\frac{3}{8}$ in. from the end of each piece, and secure them to the ends of the brass rods, as shown at A, in Fig. 141 (p. 151), to take the place of the spider arms. The ends of the coils are kept in position by these, and the wire is prevented from getting under the spider arms when they are being placed on to the ends of the armature.

When the armature is in position for winding, take the shuttle of wire, cut the insulation off the end for a distance of 1 in. or so, and secure it to the bench by a screw. Wind the wire into the channel by bringing the shuttle over the armature, and passing it back through it, starting at the left-hand side (when looking at the commutator end), winding to the right and then back again to the left, and so on till all the wire on the shuttle is wound on the armature, finishing at the right-hand side. Beat the wire regular by a small wooden mallet, or by a piece of wood struck with a hammer. The bulging of the wire on the inside is apt to be overlooked, but must be watched for carefully; otherwise, when pushing the shaft through the armature, it may damage the insulation. A galvanometer should be used, if possible, for testing the latter.

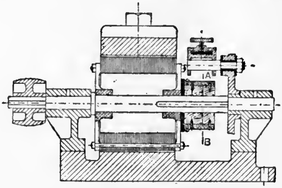


Fig. 140.—Longitudinal Section of Dynamo.

When this coil is completely wound, 3 in. being left to connect to the commutator as a temporary protection to the wire, wrap a band of calico round the coil, securing it with thread; then proceed to wind the other coils similarly. The commencing end of one coil must be soldered to the finishing end of the next, one end of the soldered wires being made into an eye, and secured to a commutator strip by means of a brass headed screw. Another method of fastening the ends of the armature coils is to solder both the wires to a short length of brass rod screwed vertically into the end of the commutator strip (*see* Fig. 54).

When all the coils are wound, take the armature off the bench, lay it on one end, remove the five pieces of wood, and put the spider on quickly and carefully, all corners on the spiders having been well rounded. Next turn the armature the other end up; place the second spider on the shaft, and put the latter through the armature and through the first spider; then remove the remaining pieces of wood. Put the spider on its place, and screw up the nuts until both the spiders are well home; then secure the nuts with soft solder.

The commutator and the spider must be separated by a vulcanite washer, $2\frac{1}{2}$ in. diameter and $\frac{1}{8}$ in. or $\frac{3}{16}$ in. thick, as shown in Fig. 140 (p. 149). The binding-wire can now be wound round the armature coils, using No. 26 B.W.G., and securing each band with solder where it crosses the iron. Insulate the bands from the armature coils by strips of tape, asbestos, or mica.

The casting for the commutator is a parallel brass cylinder, 2 in. outside diameter, $1\frac{1}{2}$ in. wide, and $\frac{1}{4}$ in. thick. This has to be mounted on a cylindrical block of insulating material, and, vulcanised fibre, ebonite, or lignum-vitæ are specially suitable. Boxwood is, however, more likely to be used. Turn a piece $2\frac{1}{4}$ in. long, and of a diameter that will allow it to be driven into the commutator casting; take care to have the grain running across the piece diameter ways, or it will split when pushing the commutator on the shaft. Cut from one end a length $\frac{5}{8}$ in. (*see* A B, in Fig. 140), while the wood is in the lathe, with the two parted surfaces quite flat. Divide the commutator casting round the outside face into twenty equal divisions by lines parallel to the axis. Ten of these lines taken alternately will show where the saw-cuts may be, the other ten where the holding-down screws must be placed. In each strip, on the latter line, three holes must be drilled, that on the extreme left, being $\frac{3}{16}$ in. tapping; the next $\frac{5}{16}$ in. away, and the third, on the extreme right, being both countersunk for a $\frac{1}{2}$-in. brass screw. When all the holes are drilled and tapped, file away all burrs and lumps from the inside of the casting, observing that the button-headed screws, which are fitted to the $\frac{3}{16}$-in. tapped holes, do not project inside the cylinder when screwed down to the head.

Warm the casting while melting some glue, which should be thin, so as to have a close joint. Then drive in the short piece of boxwood, parted face first, until flush with the end of the brass cylinder; put a little glue on the parted face of the other piece, and drive it into the open end with a mallet, so that the grain of the two pieces is at right angles when they meet in the centre of the brass casting. Directly the wood is driven home place the whole endways between the jaws of the vice, and keep it under pressure for some hours. If the grain were uniform across the cylinder, some screws fastening the commutator strips would be apt to strip; but with the grain at right angles one screw is sure to hold.

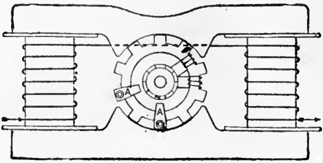


Fig. 141.—End View showing Method of Winding Armature and Fields.

When the glued joint is set quite hard, screw all the brass holding-down screws into their respective holes; then with a hack saw cut through the casting along the lines already drawn, taking care not to saw deeper than $\frac{1}{16}$ in. into the boxwood.

When all the strips are sawn apart, lift each alternate one, singly, and clean away all brass filings, etc.; then put strips of mica in the saw cuts, and jam them tight, by screwing the commutator strip home, but be careful not to put too great a strain on the brass screws.

The boxwood projects at the end carrying the button-headed screws, so that the commutator may be held in a chuck when boring the central hole. Bore this hole $\frac{7}{8}$ in., taking care not to get it too large, and working by calipers, as it is impossible to try it in place. Hand pressure is sufficient to force the commutator into place. The commutator must be driven by a vulcanite or ebonite key, fitted into the existing keyway in the shaft, but which need go no more than $\frac{1}{8}$ in. into the boxwood. When the commutator is mounted on the shaft, turn it up in the lathe, using a fine-pointed tool, and taking a very light cut; then finish up with fine glass-paper, not emery-cloth.

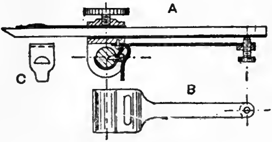


Fig. 142.—Brush Gear.

The brush rocker and brush gear are shown at Fig. 139 (p. 147), with the rocker fitted to the bearing, together with one brush and brush-holder. The brass rods to carry the holders are $\frac{1}{2}$ in. in diameter by $1\frac{1}{2}$ in. long, turned down to $\frac{3}{8}$ in. for another $1\frac{1}{2}$ in., and screwed for $\frac{3}{4}$ in. at the small end. Fig. 140 (p. 149) shows a half section of the brush rocker, with a vulcanised fibre bush and washers at each end.

Fig. 142a is a section showing an easy method of regulating the pressure of the brushes upon the commutator by means of the piece of thin spring steel. The width at the lower end of this piece of steel is exactly that of the space between the cheeks of the brush-holder, therefore, when the strip of steel is secured to the brass supporting rod by the small steel screw, there is no side-play in the brush-holder. The other end of the steel strip is ¼ in. wide and 3¾ in. long, with a nut soldered to it, and has a $\frac{3}{16}$ in. thumb-screw. The spring, shown in plan at B, is about 4¼ in. long, over all.

The brushes are held off the commutator by means of the steel tongue shown in position at A, and also in detail at C.

The end of this tongue, which is bent round at right angles, must be secured to the holder by a $\frac{3}{16}$-in. screw, the other end having a ⌓-shaped hole, so that when the brush is off the commutator this hole drops over the head of the cheese-head screw, which must have half its head partly filed down to receive it. To release the brush the tongue must be lifted with the finger off the screw-head. The larger steel spring, through which this tongue passes, then presses the brush on the commutator with a pressure that can be adjusted by means of the thumb-screw at the end of the spring. A piece of sheet steel as wide as the brush is fixed so that the thumb-screw presses against it, and a similar piece is placed on the top of the brush, extending from the brush-holder to the toe of the brush.

When the machine is ready for trial, secure it to the floor, and connect it by a 1¾-in. belt to the driving-power. Looking at the commutator end of the armature, it must run clockwise, with the brushes diametrically opposite, and pointing in the direction of rotation. Connect the end of the last coil of the left-hand field magnet to the left-hand brush, and the last or outside coil end of the right-hand field magnet to the right-hand brush, the two ends of the bottom layers of each field-magnet coil being joined together. Next connect the positive pole of a set of four Leclanché or three bichromate cells to the left-hand brush, and the negative pole to the right-hand brush. One of these wires must be cut with clean ends, so that they can, when brought in contact, complete the circuit.

Hold the two ends of this wire in the hand, and run the machine at about 1,800 revolutions per minute; then, when fully under way, touch the two ends of the wires together. If the batteries are in good condition, they ought to be strong enough to start the magnetism in the field magnets. If the dynamo begins to excite, the first thing that will be noticed is that the tone given out by the revolving armature will change from a whirr to a low humming sound; sparks also will be observed at the brushes. Directly the machine starts to excite, disconnect the battery circuit, and keep the machine running for a few minutes. Then stop and connect a 50-volt 16-candle-power or 8-candle-power lamp to the brush-holders by two wires of any convenient length. Run the machine again, and the lamp ought to light up when running at 1,800 revolutions per minute. If the machine will not excite the first time, cross the leads from the field magnets to the brushes, so that the right-hand brush is connected with the left-hand coil and the left-hand brush with the right-hand coil; then run the machine again, and if unsuccessful, try six, then eight, batteries in series to excite the field magnets; if still unsuccessful, there is a broken wire, or the insulation has given way in the armature. This must be discovered and repaired. Then connect up six more lamps of 16 candle-power each, one by one as the machine is running, and if the brushes start sparking, bring them slowly forward, by means of the rocker, in the direction of rotation until the sparking ceases. The power required to drive the machine, when under full load, will be about $\frac{3}{4}$ brake horse-power.

Not until the machine works properly should the finishing touches be put on.

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